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**CROSS-FLOW CALIBRATION AT TRANSONIC SPEEDS  
OF FOURTEEN PERFORATED PLATES WITH ROUND  
HOLES AND AIRFLOW PARALLEL TO THE PLATES**

(TITLE UNCLASSIFIED)

By

William L. Chew, PWT, ARO, Inc.

July 1955

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BY *[Signature]* *7/25/58*  
Name and Position of individual *Aug 5, 1958*

**ARNOLD ENGINEERING  
DEVELOPMENT CENTER**

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CLASSIFIED DOCUMENT

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**SUMMARY**

Cross-flow calibration tests on fourteen perforated plates with round holes were conducted in the Transonic Model Tunnel of the Propulsion Wind Tunnel Facility. The results indicate the effect of varying the wall open area, hole size, and plate thickness on the cross-flow characteristics of perforated plates with stream flow parallel to the plates. Perforated plates with 1/16-in. diameter holes and 1/16-in. plate thickness were varied in opening ratio from 5.2 percent to 33 percent. Perforated plates with an open-area ratio of 22.5 percent and hole diameters of 1/4 in., 1/2 in., and 1 in. were investigated with thicknesses varying from 1/16 in. to 1 in. The stream Mach number was varied from 0.75 to 1.175.

The results show that the slope of the cross-flow characteristic curve increased slightly as the opening ratio was increased from 5.2 percent to 33 percent for outflow velocities greater than 3 percent. Results of tests on perforated plates with an open-area ratio of 22.5 percent and variation in hole diameter from 1/4 in. to 1 in. show that the pressure differential across the plate increased as the plate thickness was decreased for a constant outflow.

Throughout the pressure differential range, regular and consistent cross-flow characteristics were obtained with perforated plates with relatively large ratios of hole diameter to plate thickness.

**NOMENCLATURE**

$\Delta p$	Pressure difference between tunnel centerline and plenum chamber
$q$	Free-stream dynamic pressure, pounds per square foot
$v$	Velocity, feet per second
$\rho$	Mass density, slugs per cubic foot

**Subscripts**

$h$	Hole conditions
$\infty$	Free-stream conditions

## INTRODUCTION

Recent analysis and experimental results have indicated that a promising transonic test-section configuration is one in which perforated walls are used. In order to develop an optimum test-section configuration, extension of the knowledge of the characteristics of perforated test-section walls - particularly the knowledge of the resistance to cross flow through the walls - is necessary.

Calibration studies were made on fourteen perforated-plate configurations with round holes to determine the effect of variations in wall open-area ratios, hole size, and plate thickness on the cross-flow characteristics of perforated plates with flow parallel to the plate. From the results of these tests the relation between pressure drop across the wall and the normal flow velocity through the perforations may be obtained.

## TEST DESCRIPTION

### TUNNEL

The tests were conducted in the Transonic Model Tunnel of the Propulsion Wind Tunnel Facility. A general description of the tunnel and its components is given in Ref. 1. The test-section configuration used for these tests consisted of solid parallel side walls with the various perforated plates installed in the movable top and bottom walls to form the other two sides. All test Mach numbers were established with a sonic nozzle and auxiliary suction; the movable diffuser flaps were in the closed position during all tests. It was necessary to produce both inflow and outflow quantities of air to the test section to attain the range of pressure differentials reported herein. When inflow of air to the test section was necessary, the auxiliary-suction line was opened to the atmosphere, and

flow-measuring instrumentation was reversed. Stagnation temperatures were normally in excess of  $140^{\circ}\text{F}$  with a resulting average Reynolds number of  $5.3 \times 10^6$  per foot.

## WALL CONFIGURATIONS

The fourteen perforated plates used in these tests had circular holes drilled normal to the plate. Variations in the configurations included changes in the wall open-area ratio, hole diameter, and the wall plate thickness. The perforated plates extended the entire length of the test-section top and bottom walls. Table 1 lists the perforated plates tested and the various parameters. Taper strips (as described in Ref. 1) were installed on the initial upstream portion of the perforated walls for all the configurations except the 5.2-percent open-area walls.

Four of the configurations had open-area ratios of 5.2, 11.8, 22.5 and 33 percent. The hole diameter and plate thickness for these four configurations were 1/16-in. The holes were arranged in a staggered pattern with each line of holes aligned with the flow direction. The perforated material used for these four configurations was commercially available. Photographs of the material with the various open-area ratios are shown in Fig. 1.

The perforated-wall configurations with a constant open-area ratio of 22.5 percent were fabricated with hole diameters of 1/4 in., 1/2 in., and 1 inch. The plate thickness was varied from 1/16 in. to 1 inch. The plate thickness used with each of the various hole diameters is shown in Table 1.

Table 1. Geometry of Perforated Plates

Item	Hole Diameter (Inches)	Plate Thickness (Inches)	Porosity (%)	<u>Hole Diameter</u> <u>Plate Thickness</u>
1	1/16	1/16	5.2	1
2	1/16	1/16	11.8	1
3	1/16	1/16	22.5	1
4	1/16	1/16	33.0	1
5	1/4	1/16	22.5	4
6	1/4	1/4	22.5	1
7	1/4	1/2	22.5	0.50
8	1/4	1	22.5	0.25
9	1/2	1/16	22.5	8
10	1/2	1/2	22.5	1
11	1/2	1	22.5	0.50
12	1	1/16	22.5	16
13	1	3/8	22.5	2.67
14	1	1	22.5	1

The three basic perforated plates with 1/4-in., 1/2-in., and 1-in. diameter holes were fabricated from 1/16-in. thick aluminum alloy. The thickness was increased to 1 in. by bonding wood to the plenum-chamber side of each test wall. The hole pattern was drilled through the entire thickness. The desired thickness from 1 in. to 1/16 in. was then obtained by planing the wood. The holes were drilled in a staggered pattern with the pattern rotated 15 degrees from the direction of flow rather than aligned with the flow. The hole pattern was rotated 15 degrees to avoid having continuous lengths of solid plate in the direction of the stream lines. A photograph of each basic hole pattern may be seen in Fig. 2. The orientation of the hole pattern of the various test plates differed, as may be noted from Figs. 1 and 2.

#### TEST PROCEDURE

In determining the cross-flow characteristic of each perforated plate, it was necessary to measure the pressure differential across the wall and the auxiliary-suction quantities. The pressure differential was determined by taking the difference between the measured plenum-chamber static pressure and the average static pressure along the tunnel centerline. Static pressures along the tunnel centerline were measured, using an axial static-pressure probe with orifices located at 2-in. intervals. The plenum-chamber static pressure was measured by a static orifice located in the plenum-chamber shell. Pressure measurements were recorded by photographing a multitube mercury manometer.

Both positive and negative values of pressure differentials across the walls were obtained by varying the top and bottom wall angles. Each wall was varied from approximately 60 minutes convergence to approximately 60 minutes divergence. The range of pressure differential obtained in these tests varied from a

negative value of approximately 2 percent of stream dynamic pressure to positive values up to approximately 14 percent. Test Mach numbers of 0.75 to 1.175 were obtained for each wall-angle setting. Uniform flow was established in the test section for each test Mach number by adjusting the suction quantity and tunnel pressure ratio.

Inflow of air to the test section from the plenum chamber at negative pressure differentials was accomplished by using the auxiliary-suction line to bleed air from the atmosphere into the plenum chamber. Inflow and outflow were measured by the use of a series of calibrated plate orifices.

## RESULTS

### GENERAL DISCUSSION

The cross-flow characteristic of each perforated-wall configuration is presented as a variation in pressure differential across the wall (referenced to free-stream dynamic pressure) with the ratio of flow per unit area through the holes. For various differential pressures, the ratio of weight flow through the walls to the tunnel flow through the nozzle was determined. With constant density assumed, the cross-flow velocity ratio through the holes in each plate was obtained by multiplying the weight-flow ratio by the ratio of the tunnel cross-sectional area at the nozzle exit to the total open area of the perforated wall.

### OPEN AREA

The cross-flow characteristics of the four configurations with opening ratios of 5.2, 11.8, 22.5, and 33 percent are presented in Figs. 3a to 3f for Mach numbers 0.75 to 1.175. In each configuration the wall thickness was the same as the hole diameter of 1/16 in. The cross-flow characteristics of the 5.2-percent and

11.8-percent open-area ratio walls were steady and regular throughout the range of velocity ratios and Mach numbers. The results from the 22.5-percent and 33-percent open-area ratio walls indicate that at outflow velocities of less than 3 percent of stream velocity, the cross-flow characteristics became irregular. This was probably caused by an unsteady boundary layer. As soon as a sufficient amount of boundary layer was removed, the cross-flow characteristics became regular as is evident for outflow velocities above 3 percent. For outflow velocities greater than 3 percent the data indicate that the slope of the curve for each wall configuration increased as the opening ratio was increased.

#### PLATE THICKNESS

The cross-flow characteristics of the three 22.5-percent open-area ratio wall configurations with 1/4-in., 1/2-in., and 1-in. diameter holes are shown in Figs. 4, 5, and 6, respectively. In each figure the results of varying the plate thickness from 1/16 in. to 1 in. are presented. The data indicate that as the thickness for each plate is reduced, the pressure differential across the plate increases. Thus, as the ratio of the hole diameter to plate thickness increases, the pressure drop through the wall increases for all positive outflow velocities and positive pressure differentials over the range tested. The characteristics are regular and steady throughout the range of pressure differentials without any adverse distribution at low value of pressure differentials and outflow velocities. It is of interest to note the displacement of the experimental curve to the right of the origin. Similar results were reported in Ref. 2 and are described as a result of mixing at the boundary.

## HOLE SIZE

To determine the effect of hole size on the cross-flow characteristics of a perforated wall, the plate thickness was held constant (1/16 in.) and the hole size was varied from 1/16 to 1/4, 1/2, and 1 inch in diameter. This resulted in a change in the ratio of hole diameter to plate thickness from 1 for the 1/16-in. diameter hole to 16 for the 1-in. diameter hole. The results of the effect of hole size on the cross-flow characteristics are presented in Figs. 7a to 7f for Mach numbers of 0.75 to 1.175. At each Mach number, the results indicate that for plates with holes larger than 1/16 in., the cross-flow characteristics were regular and steady throughout the pressure differential range. In contrast to the behavior of the walls with large holes, the wall with small holes (1/16 in.) showed irregular characteristics at small outflow velocities in the subsonic speed range. This irregular characteristic occurs when the wall boundary layer becomes large relative to the hole size. Under such circumstances, the thin airfoil theory as applied to flows through such walls (Ref. 3) is obviously no longer valid.

As soon as the wall boundary layer is sufficiently thinned through the application of larger suction, the cross-flow characteristic becomes regular. For outflow velocities greater than 3 percent, the pressure drop across the walls increased as the hole size increased. These data thus indicate that regular and steady cross-flow characteristics are obtained when walls with large ratios of hole diameter to wall thickness are used.

## HOLE DIAMETER/PLATE THICKNESS = 1

The effect of increasing the hole size on the cross-flow characteristics when maintaining a constant ratio of hole diameter to wall thickness is presented in Figs. 8 and 9. The opening ratio of the walls was 22.5 percent. When the ratio of hole diameter to plate thickness was unity the hole diameter was increased from 1/4 to 1/2 and 1-in. diameters (Fig. 8). The hole diameter was increased from 1/4 to 1/2 in. when the ratio of hole diameter to plate thickness was 0.5 (Fig. 9). The results of Figs. 8 and 9 indicate that if the boundary-layer thickness is negligibly small and the ratio of hole diameter to plate thickness is kept constant, the influence of hole size on the cross-flow characteristic is small.

## MACH NUMBER

To indicate the influence of the parallel flow Mach number on the cross-flow characteristics of a 22.5-percent open-area wall, the results for the thin wall (1/16 in.) with the various hole diameters (1/16, 1/4, 1/2, and 1 in.) have been plotted in Figs. 10a to 10d. In Fig. 10a, which shows the results for the plate with 1/16-in. holes, the irregular characteristics noted previously for some configurations at outflow velocities below 3 percent tend to obscure any variation due to Mach number. At outflow velocities above 3 percent, the influence of Mach number is small; however, there is a slight increase in the slope of the curves as the Mach number increases above 1.0. In Fig. 10b the results for the plate with 1/4-in. holes show only a small Mach number influence in the subsonic-speed range. The slope of the characteristic curve increases, however, as the Mach number is increased above 1.0 for outflow velocities above 4 percent. The results for the wall with 1/2-in. diameter holes are presented in Fig. 10c. These results show little effect of Mach number in the subsonic-speed

range. The slope increases as the Mach number increases above 1.0. This figure also shows that the wall characteristics are regular and steady throughout the pressure drop range for all Mach numbers listed from 0.75 to 1.175. When the hole size is increased to 1 inch in diameter, a similar influence of Mach number on the wall cross-flow characteristics may be noted, as is shown in Fig. 10d.

### CONCLUSIONS

The results of tests to determine the cross-flow characteristics of a series of fourteen perforated plates with round holes may be summarized as follows:

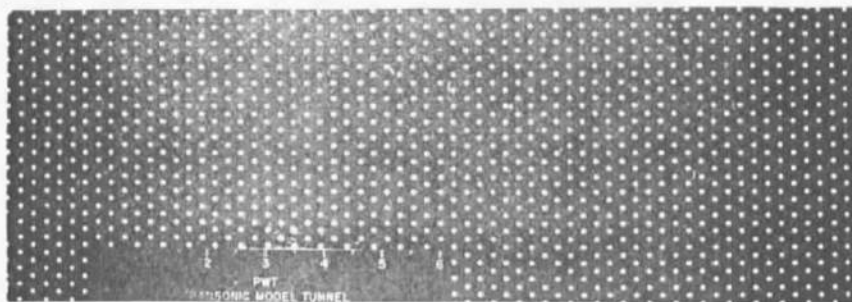
1. The slope of the characteristic pressure drop curves,  $\frac{\Delta p}{q_\infty} = f\left(\frac{(\rho v)_h}{(\rho v)_\infty}\right)$ , increased slightly as the opening ratio increased from 5.2 percent to 33 percent (1/16-in. diameter holes and plate thickness) for outflow velocities greater than 3 percent of stream velocity for all Mach numbers tested. Irregular characteristics occurred for opening ratios of 22.5 percent and 33 percent for outflow velocities corresponding to  $(\rho v)_h / (\rho v)_\infty$  values of less than 0.03.
2. For a constant outflow velocity the pressure drop increased when the plate thickness was reduced from 1 in. to 1/16 in. for a 22.5-percent open-area wall with either 1/4, 1/2, or 1 in. diameter holes.
3. An increase in the hole diameter from 1/16 in. to 1 in. for a 22.5-percent open-area perforated plate 1/16-in. thick, increased the pressure drop across the wall for a constant outflow velocity greater than 2 percent.
4. Regular and consistent cross-flow characteristics were obtained with perforated walls with large ratios of hole diameter to plate thickness.

5. The influence of hole size on the cross-flow characteristics is small when a constant ratio of hole diameter to plate thickness is maintained, provided that the holes are relatively large in comparison to the boundary-layer thickness.
6. The influence of Mach number on the cross-flow characteristics of various perforated plates is small in the subsonic range. The slope of the characteristic curve increases slightly as the Mach number is increased above 1.0.

#### REFERENCES

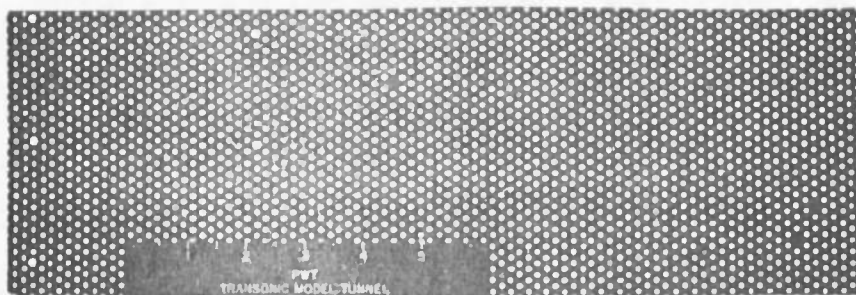
1. Gardenier, Hugh E. "Description of the Transonic Model Tunnel - Arnold Engineering Development Center." AEDC-TR-54-70, May 1955.
2. Maeder, Paul F. "Investigation of the Boundary Conditions at a Perforated Wall." Brown University, Division of Engineering, Technical Report WT 9, May 1953. (Confidential).
3. Goethert, B. H. "Flow Establishment and Wall Interference in Transonic Wind Tunnels." AEDC-TR-54-44, June 1954.

FLOW →



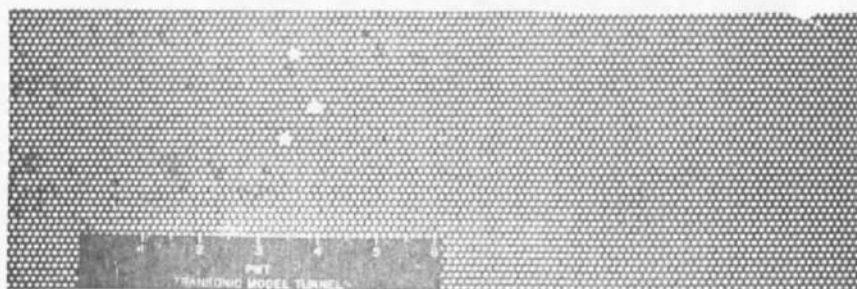
5.2 PERCENT  
1/16-in. Hole  
1/16-in. Thickness

FLOW →



11.8 PERCENT  
1/16-in. Hole  
1/16-in. Thickness

FLOW →



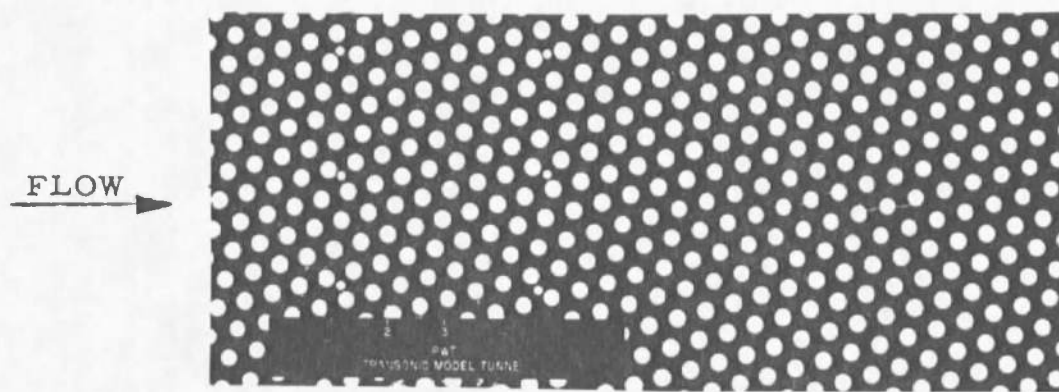
22.5 PERCENT  
1/16-in. Hole  
1/16-in. Thickness

FLOW →

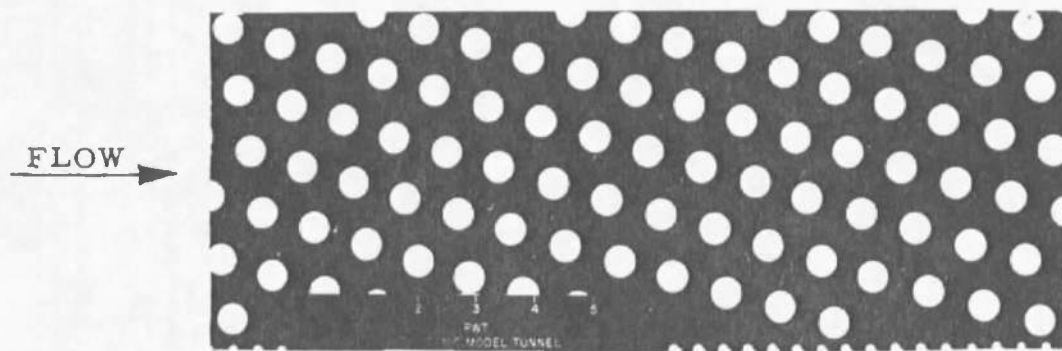


33 PERCENT  
1/16-in. Hole  
1/16-in. Thickness

Fig. 1. Four Perforated Plates with Various Percentages of Open-Area Ratio



1/4-IN. DIAMETER HOLES



1/2-IN. DIAMETER HOLES



1-IN. DIAMETER HOLES

Fig. 2. Three 22.5-Percent Open-Area Ratio Perforated Plates with Various Hole Diameters

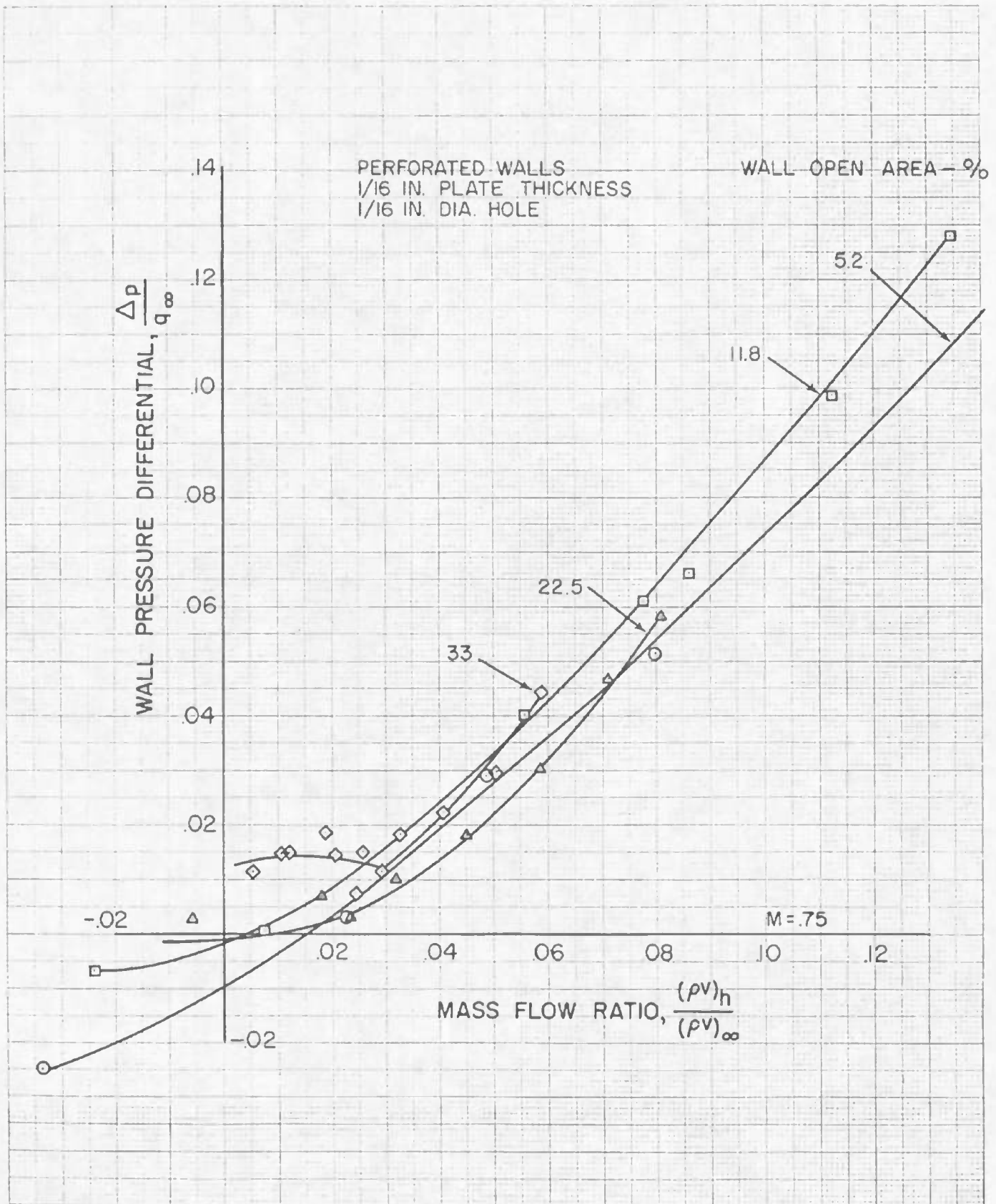


Fig. 3a. Influence of Wall Open Area on the Cross-Flow Characteristics of Four Perforated Walls with Open-Area Ratios of 5.2 to 33 Percent; M = 0.75

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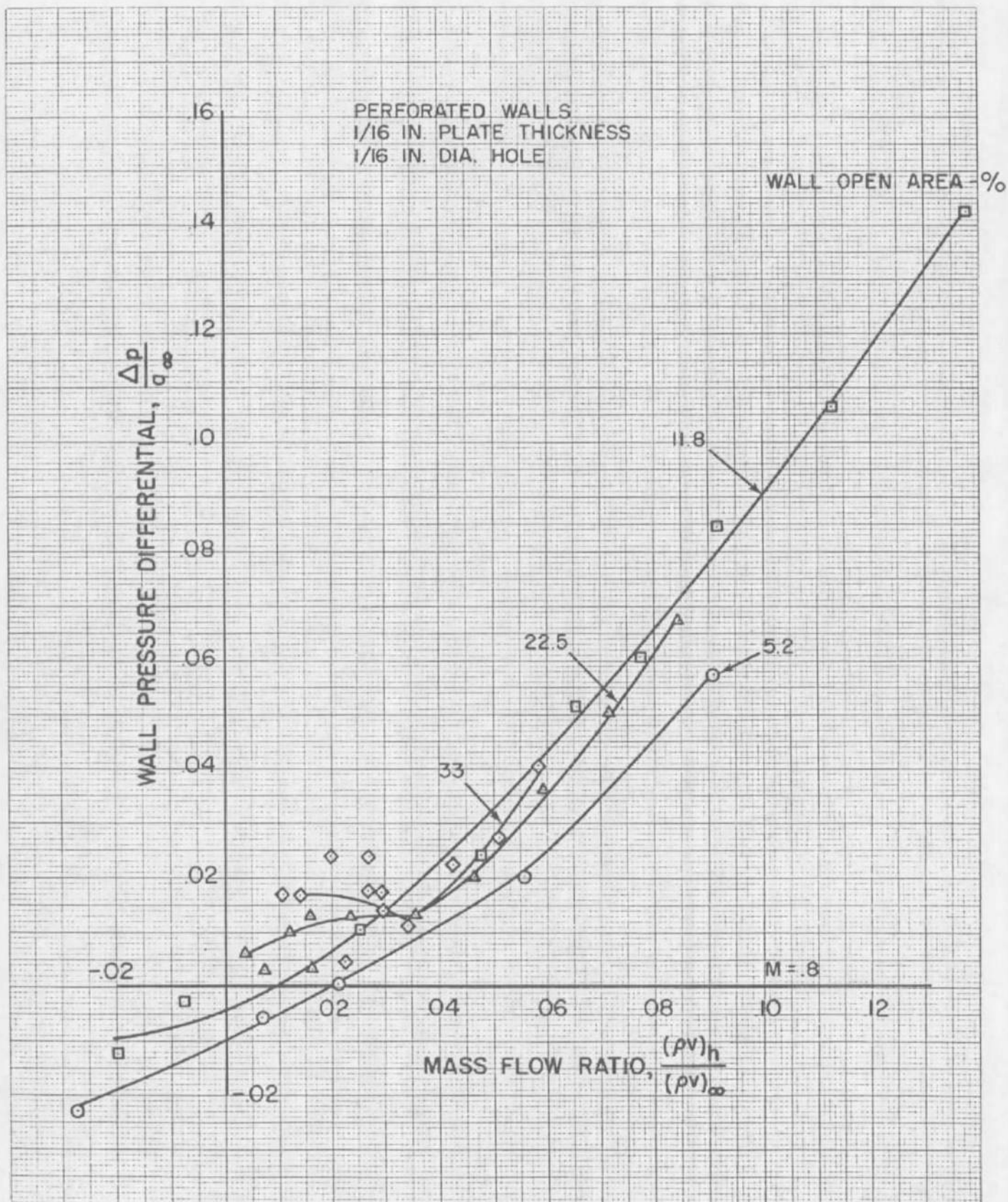
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Fig. 3b. Influence of Wall Open Area on the Cross-Flow Characteristics of Four Perforated Walls with Open-Area Ratios of 5.2 to 33 Percent; M = 0.80

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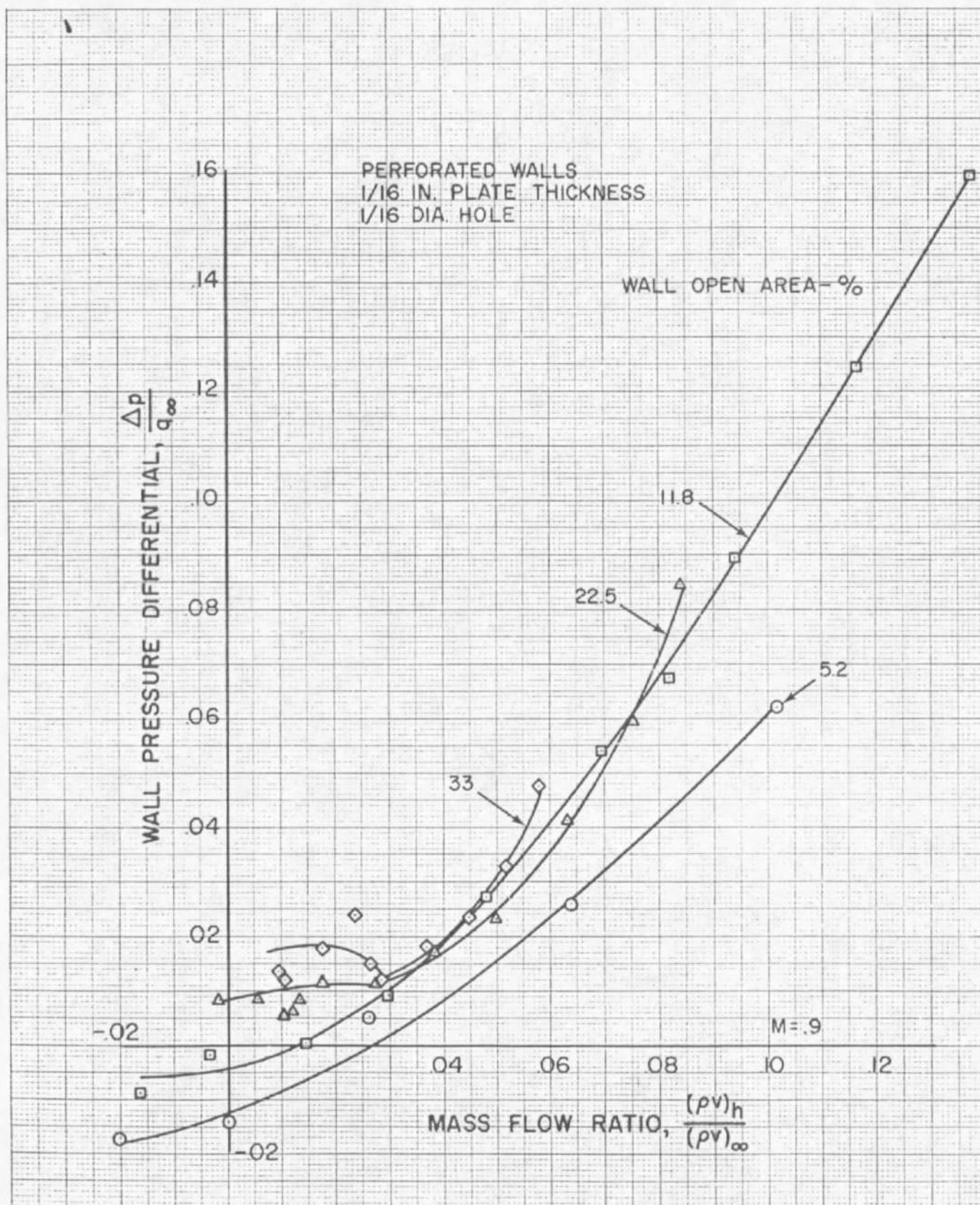


Fig. 3c. Influence of Wall Open Area on the Cross-Flow Characteristics of Four Perforated Walls with Open-Area Ratios of 5.2 to 33 Percent;  $M = 0.90$

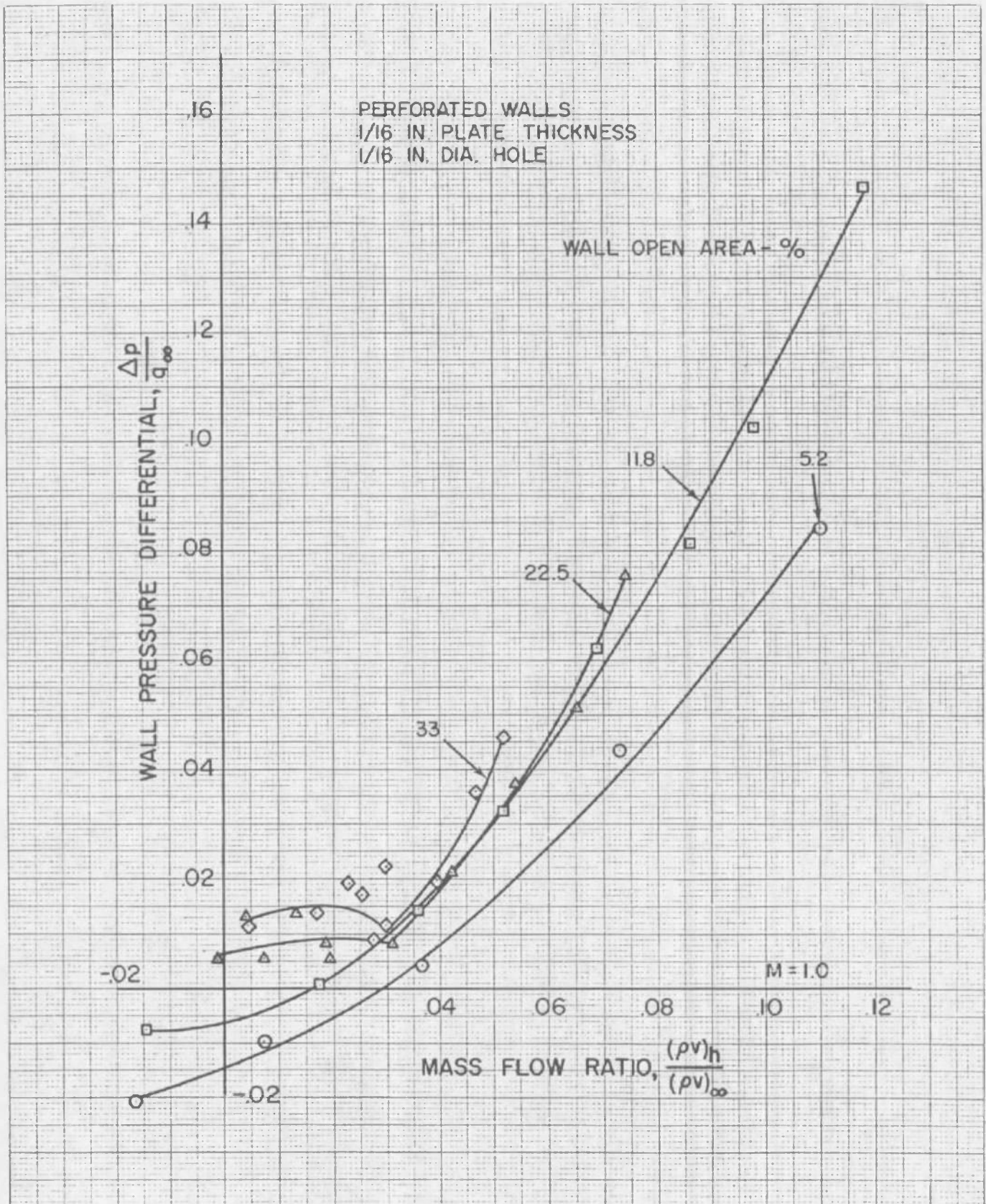


Fig. 3d. Influence of Wall Open Area on the Cross-Flow Characteristics of Four Perforated Walls with Open-Area Ratios of 5.2 to 33 Percent;  $M = 1.0$

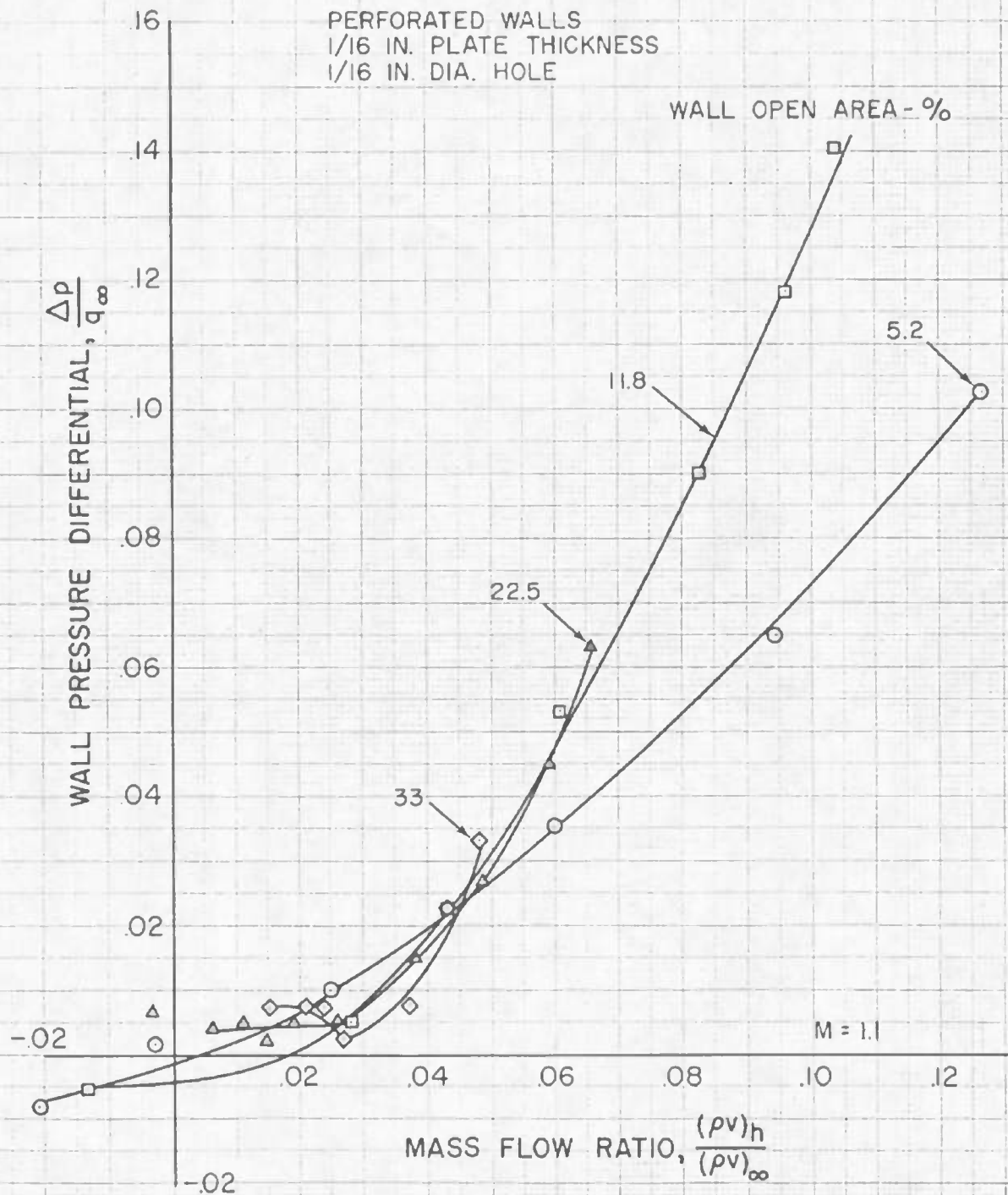


Fig. 3e. Influence of Wall Open Area on the Cross-Flow Characteristics of Four Perforated Walls with Open-Area Ratios of 5.2 to 33 Percent; M = 1.1

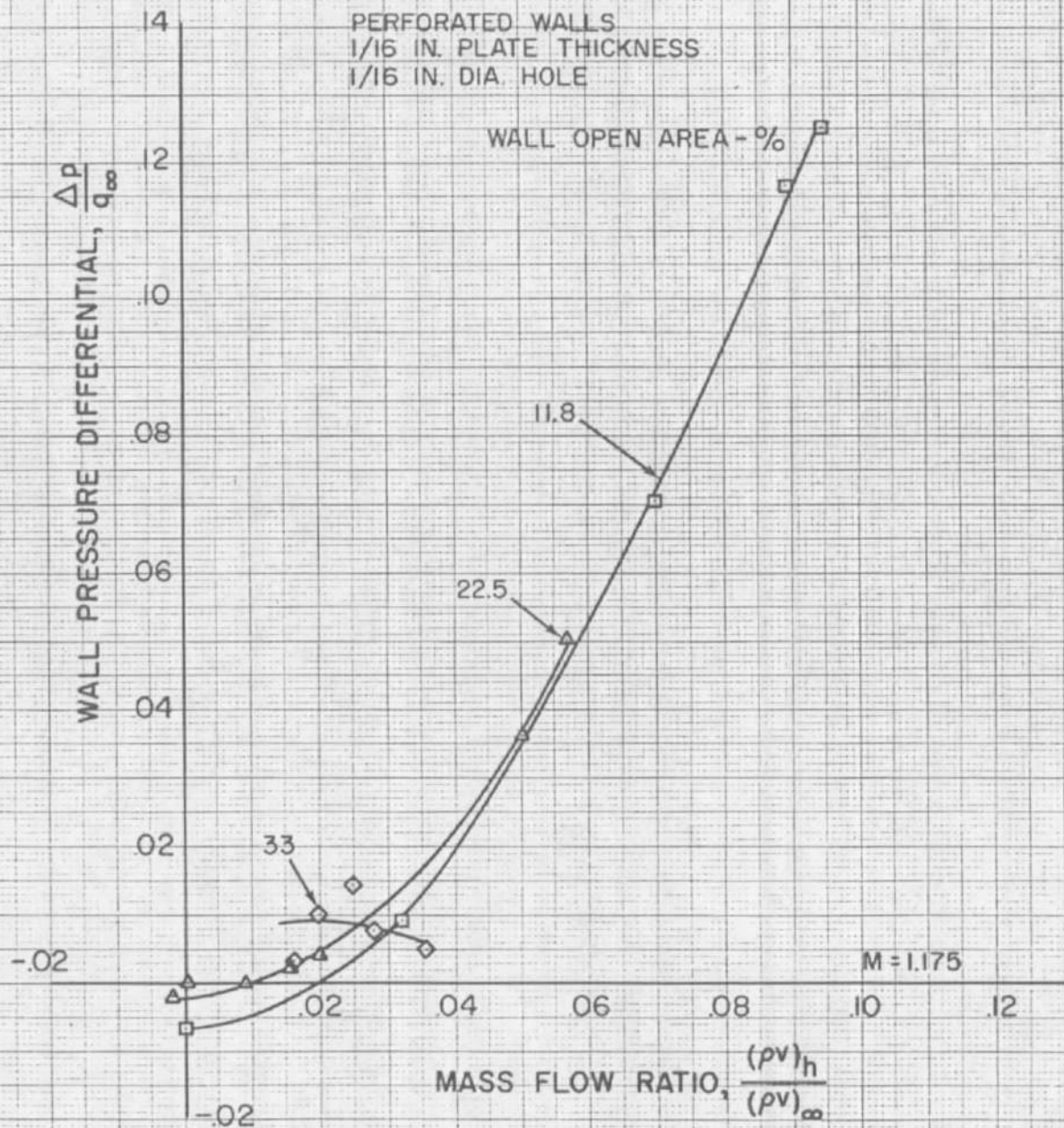


Fig. 3f. Influence of Wall Open Area on the Cross-Flow Characteristics of Four Perforated Walls with Open-Area Ratios of 5.2 to 33 Percent; M = 1.175

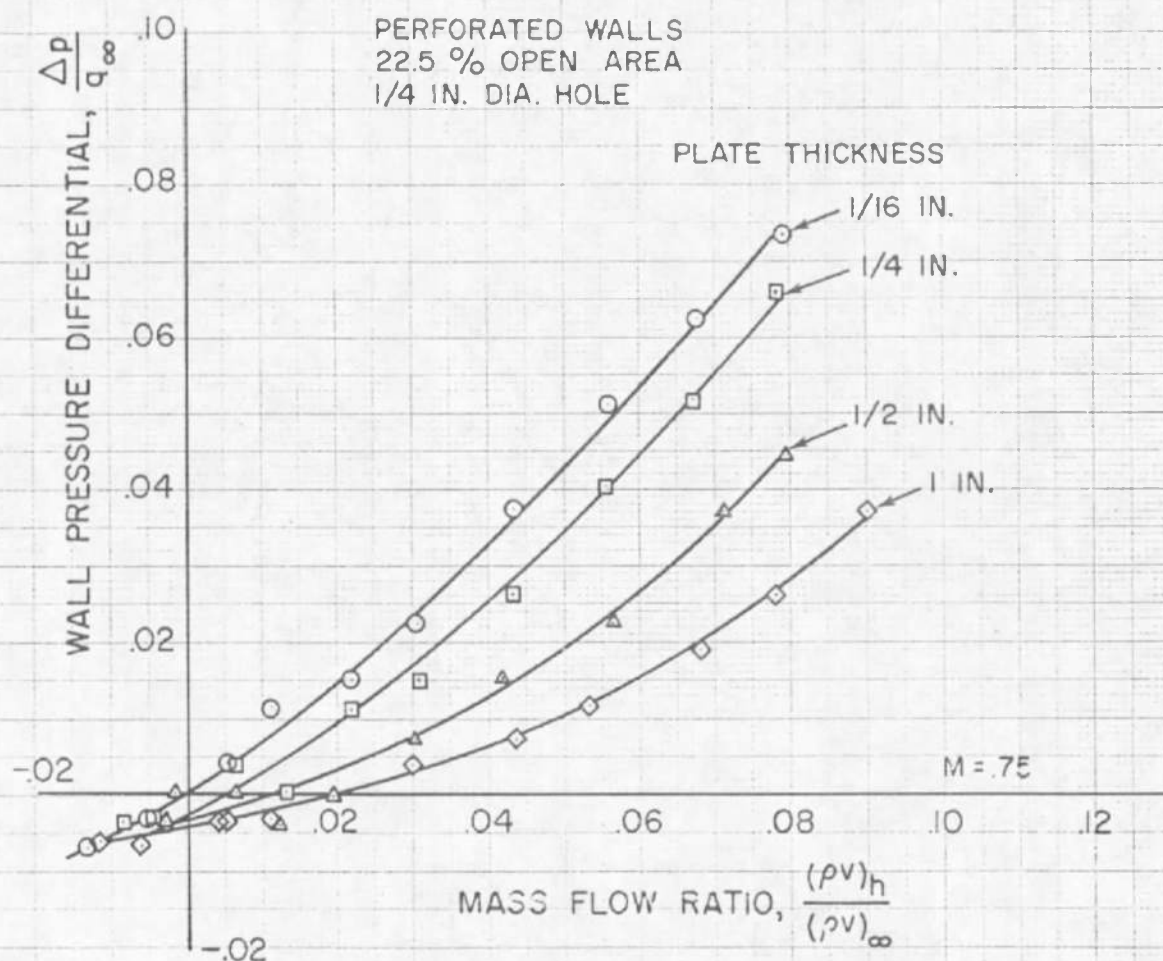


Fig. 4a. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1/4-Inch Diameter Holes;  $M = 0.75$

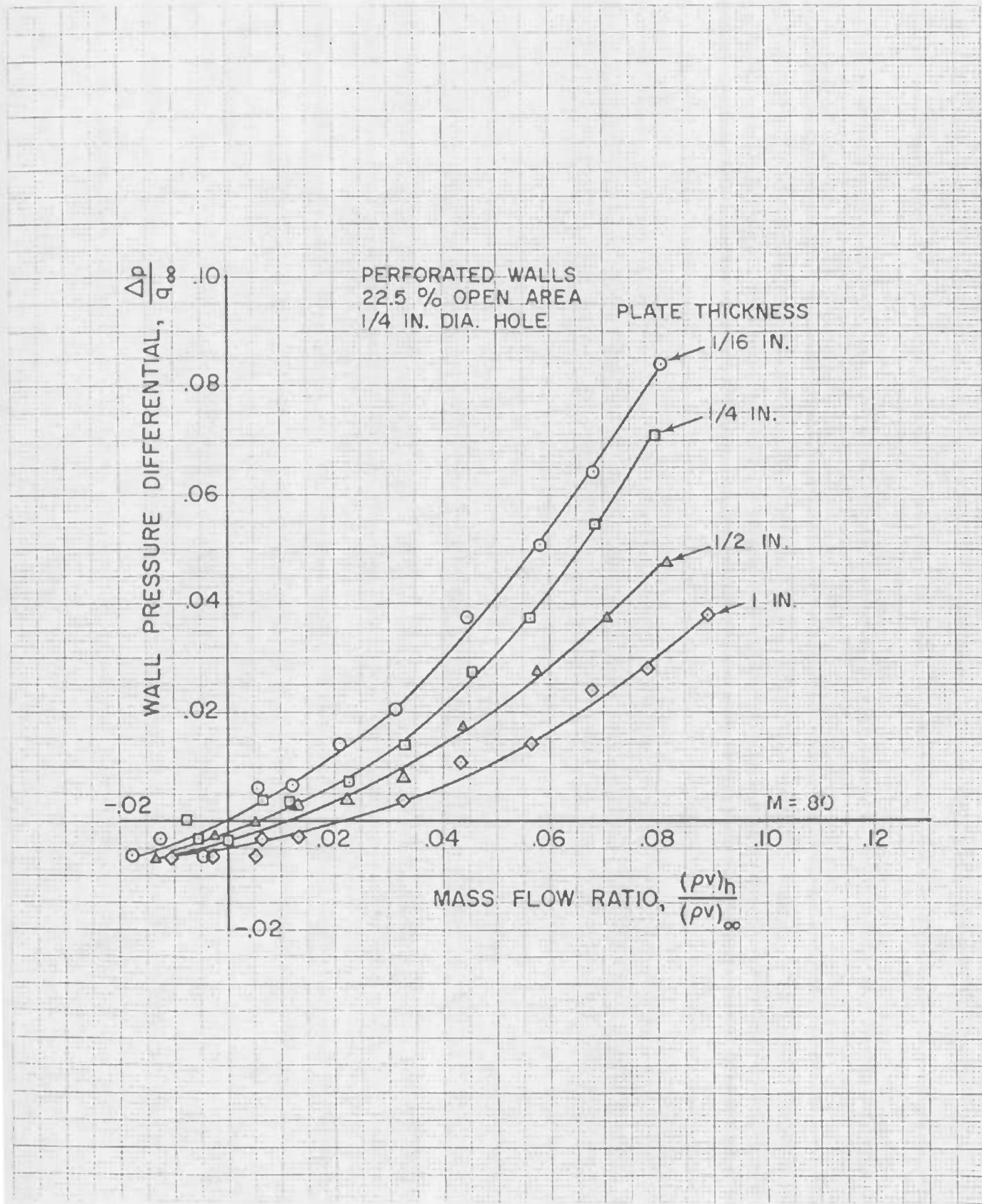


Fig. 4b. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1/4-Inch Diameter Holes;  $M = 0.80$

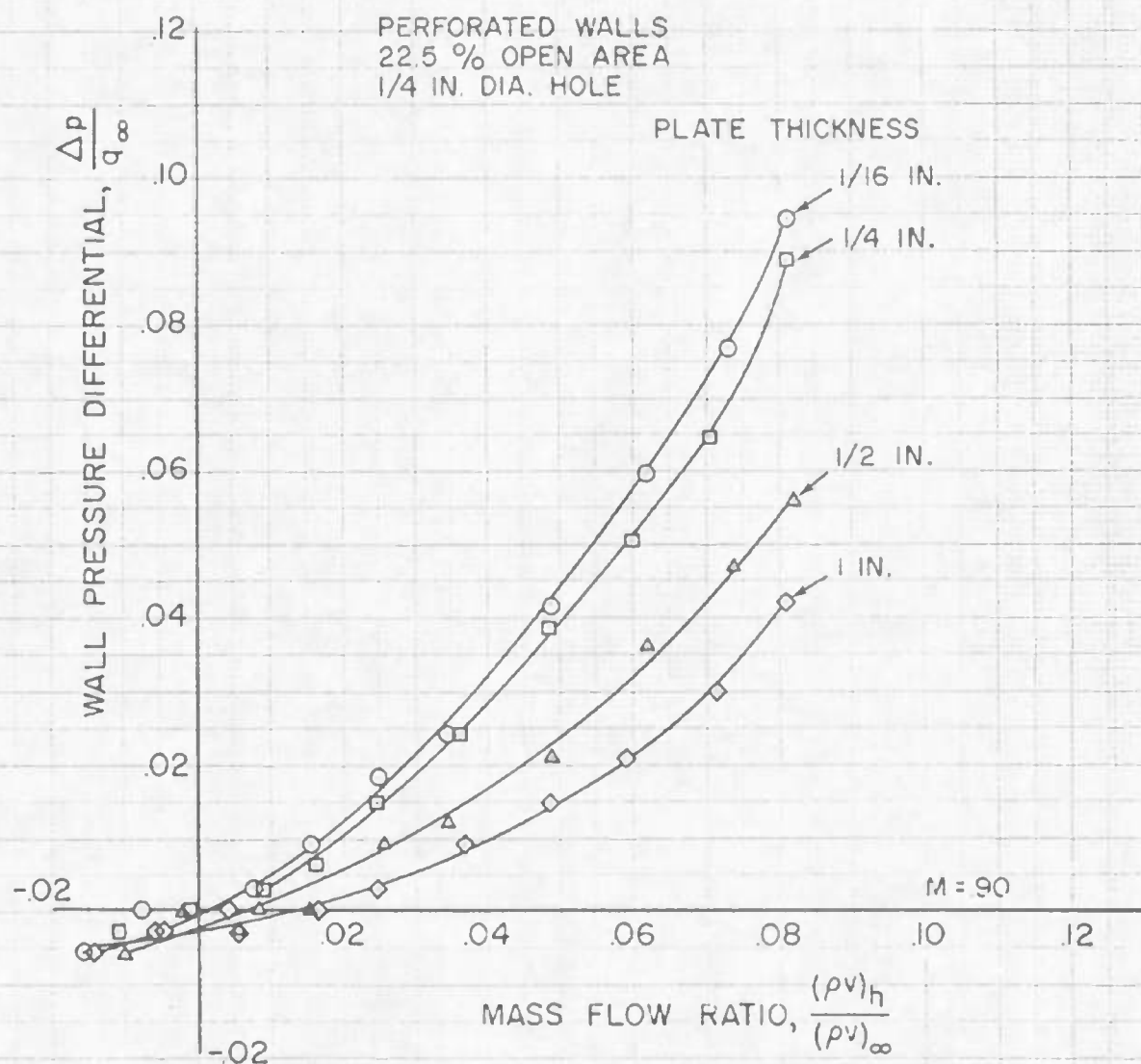


Fig. 4c. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1/4-Inch Diameter Holes;  $M = 0.90$

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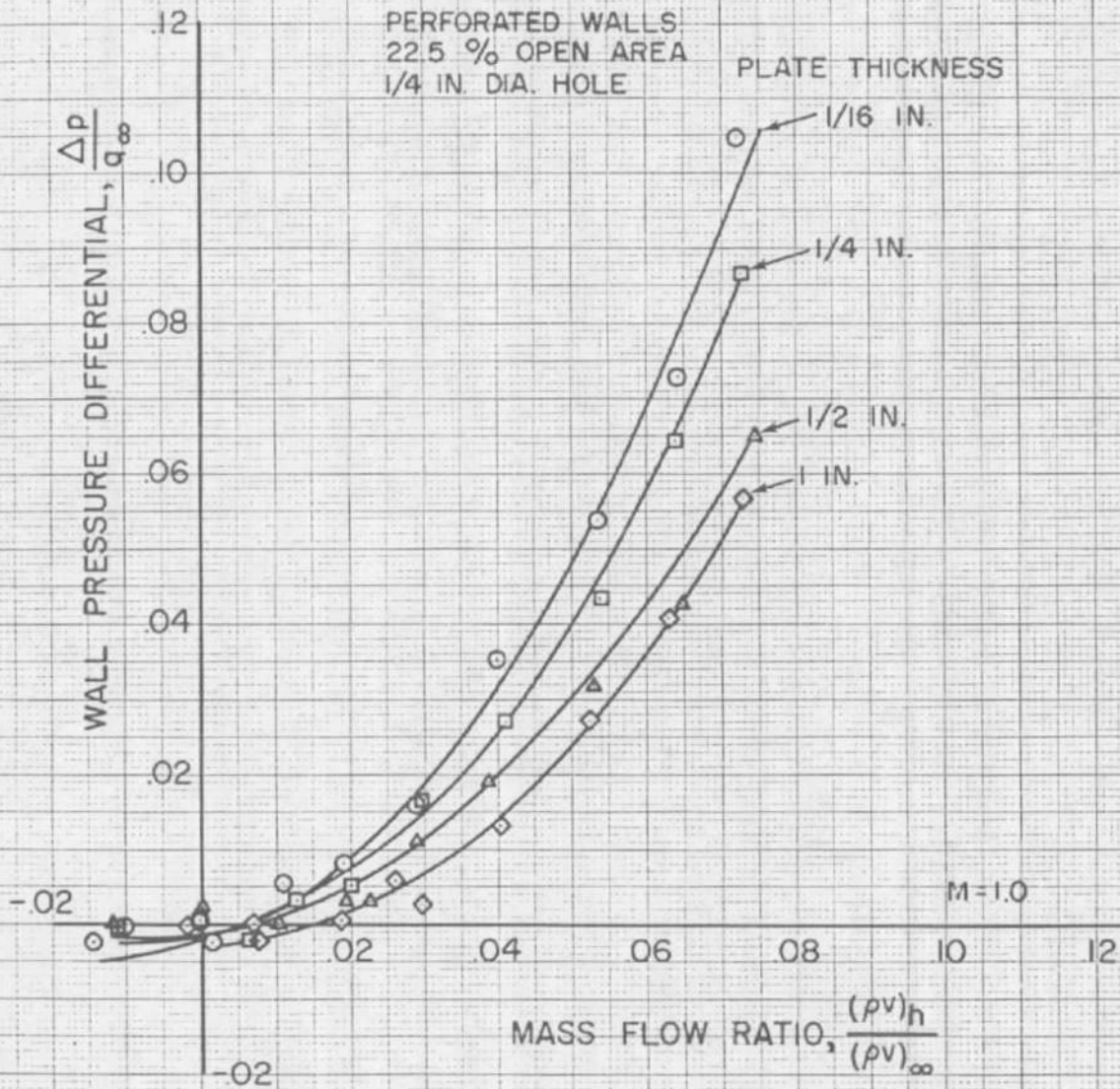


Fig. 4d. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1/4-Inch Diameter Holes;  $M = 1.0$

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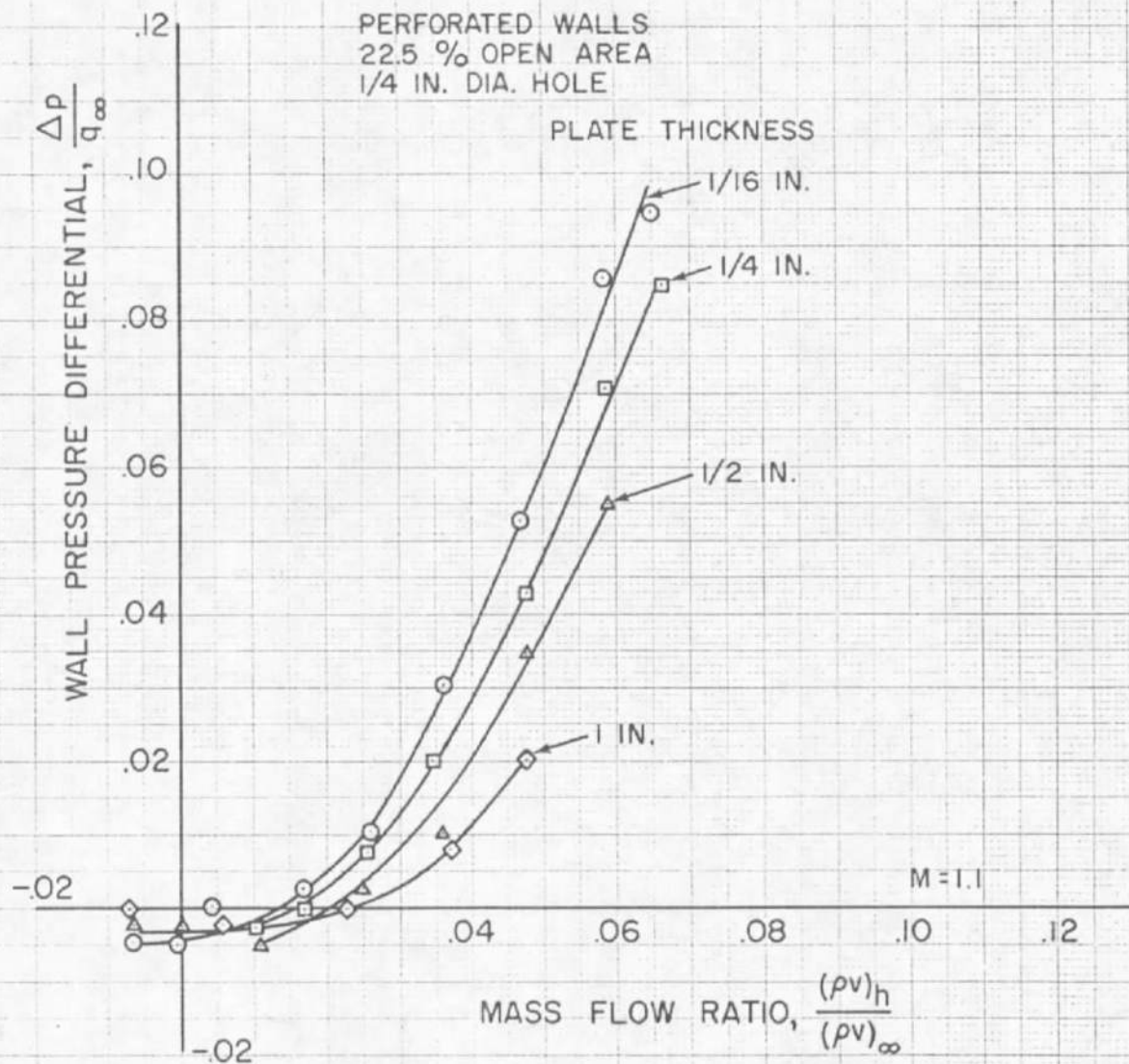


Fig. 4e. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1/4-Inch Diameter Holes;  $M = 1.1$

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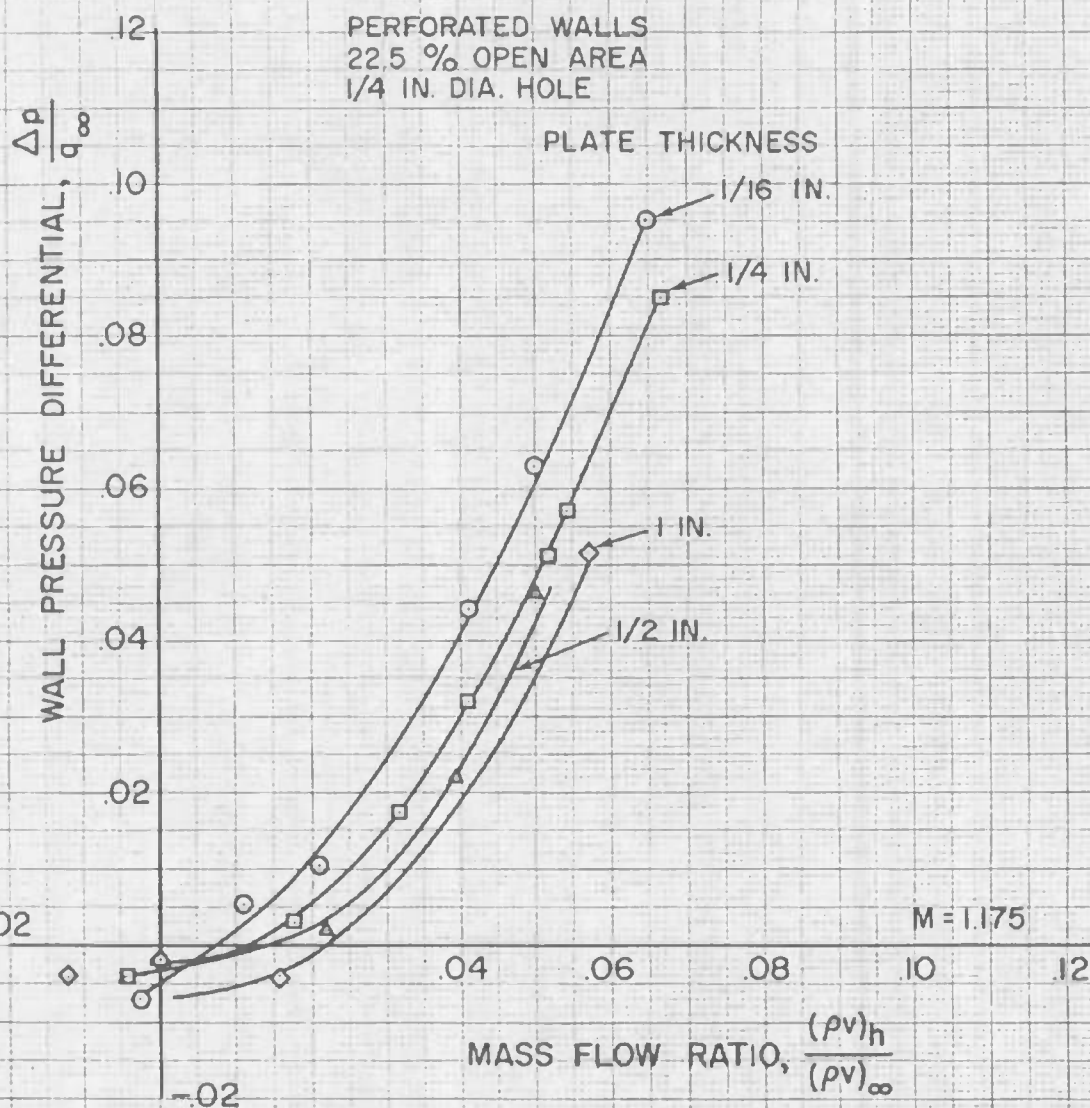
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Fig. 4f. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1/4-Inch Diameter Holes;  $M = 1.175$

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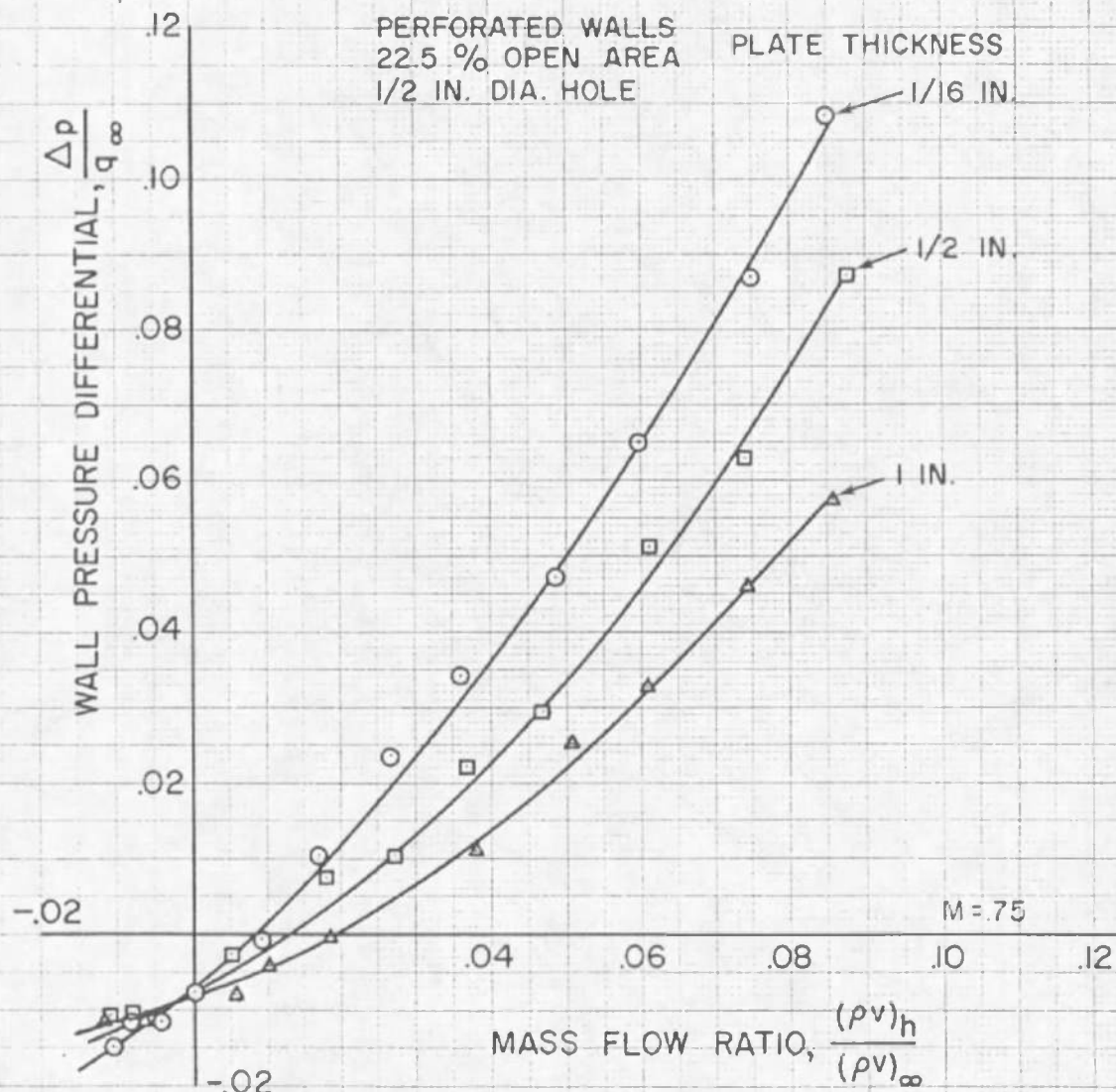


Fig. 5a. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1/2-Inch Diameter Holes;  $M = 0.75$

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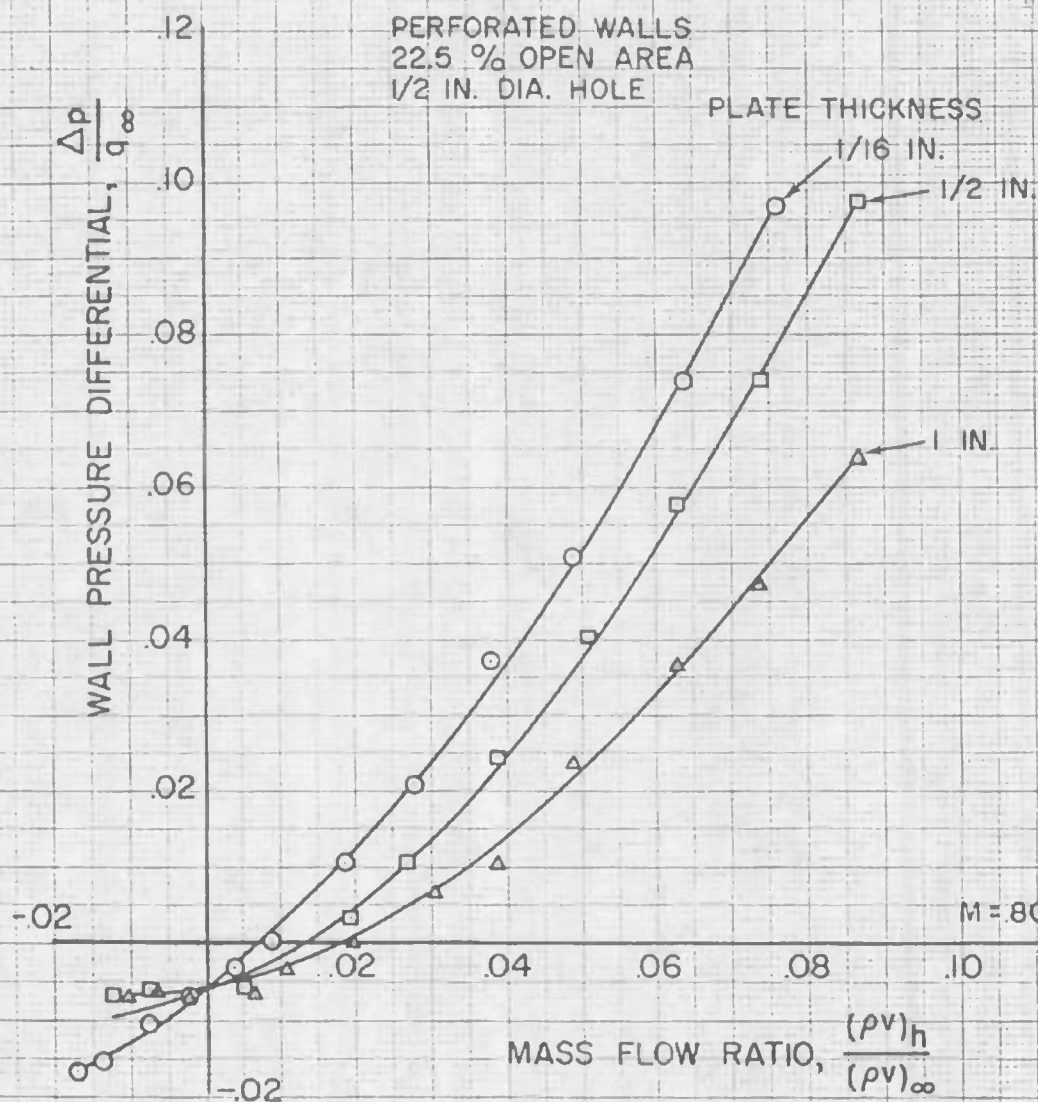


Fig. 5b. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1/2-Inch Diameter Holes;  $M = 0.80$

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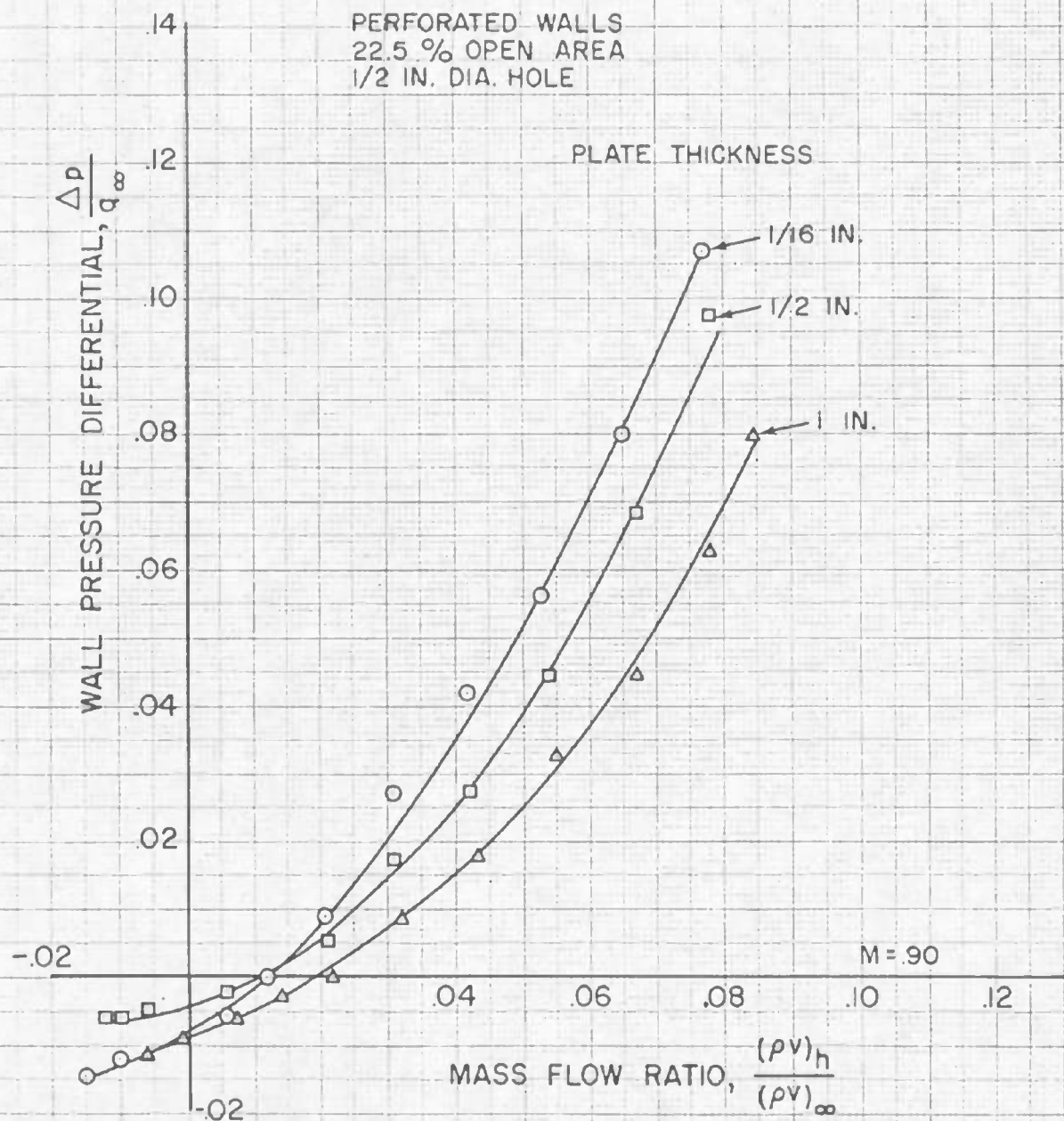


Fig. 5c. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1/2-Inch Diameter Holes; M = 0.90

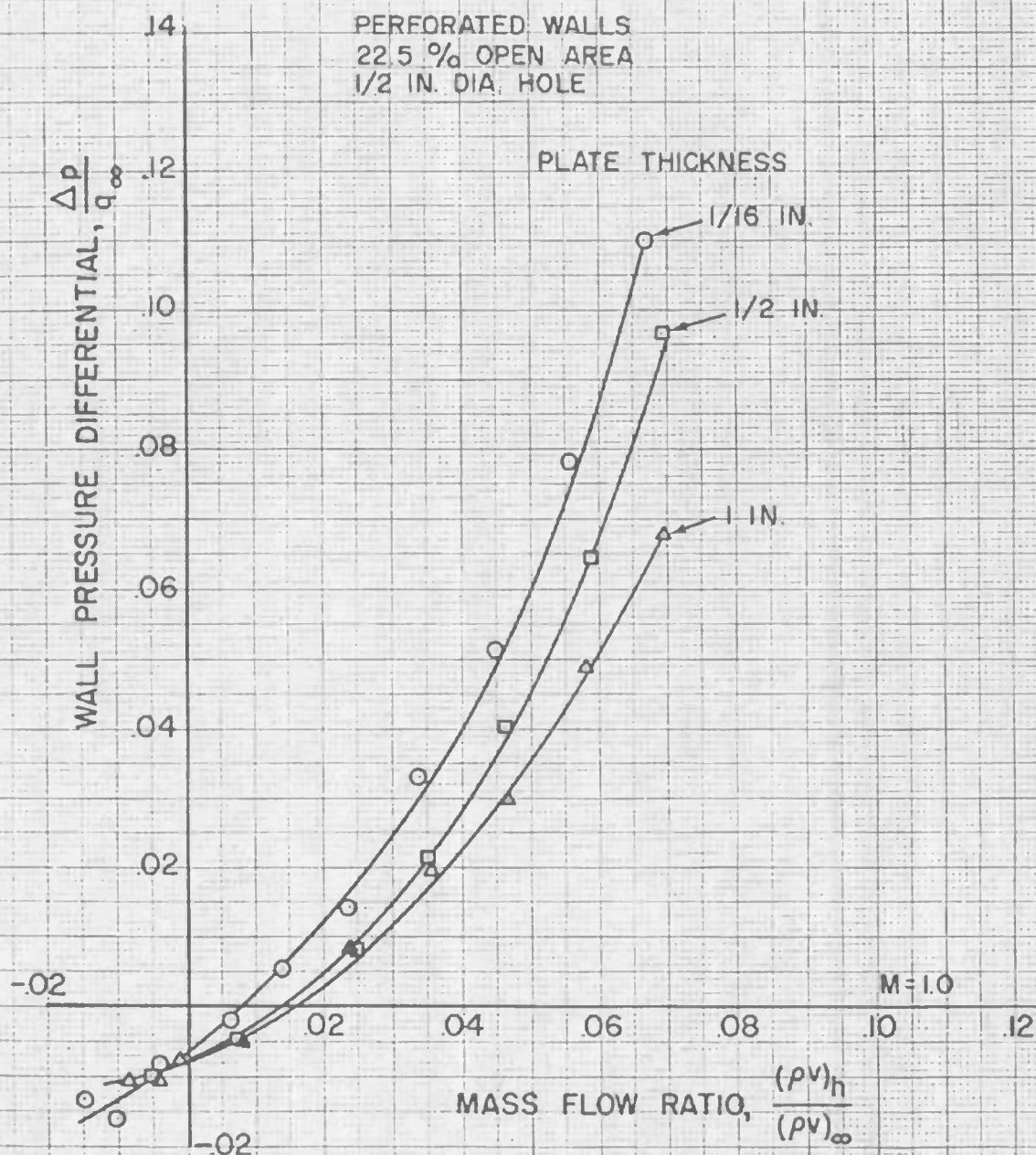


Fig. 5d. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1/2-Inch Diameter Holes;  $M = 1.0$

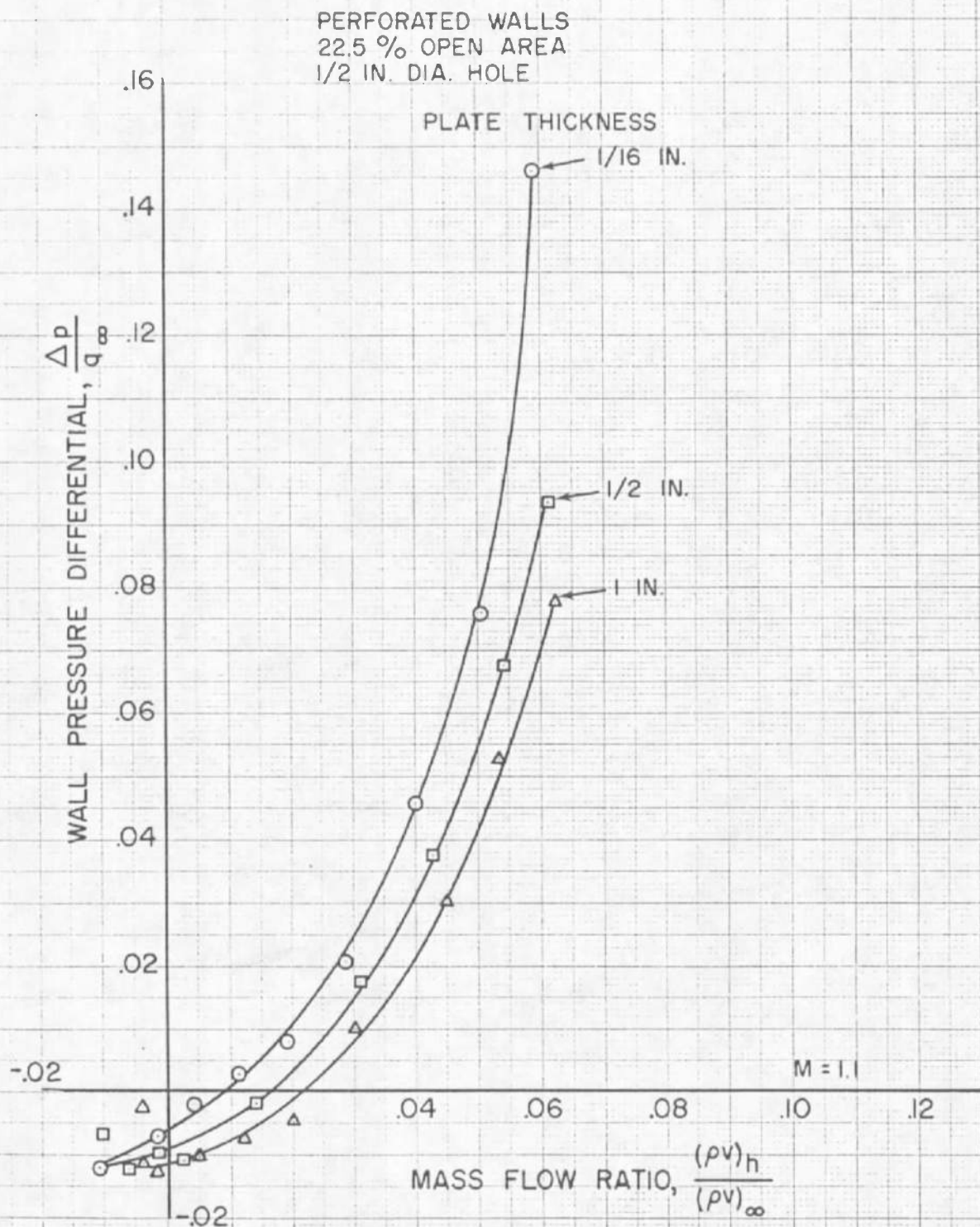


Fig. 5e. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1/2-Inch Diameter Holes;  $M = 1.1$

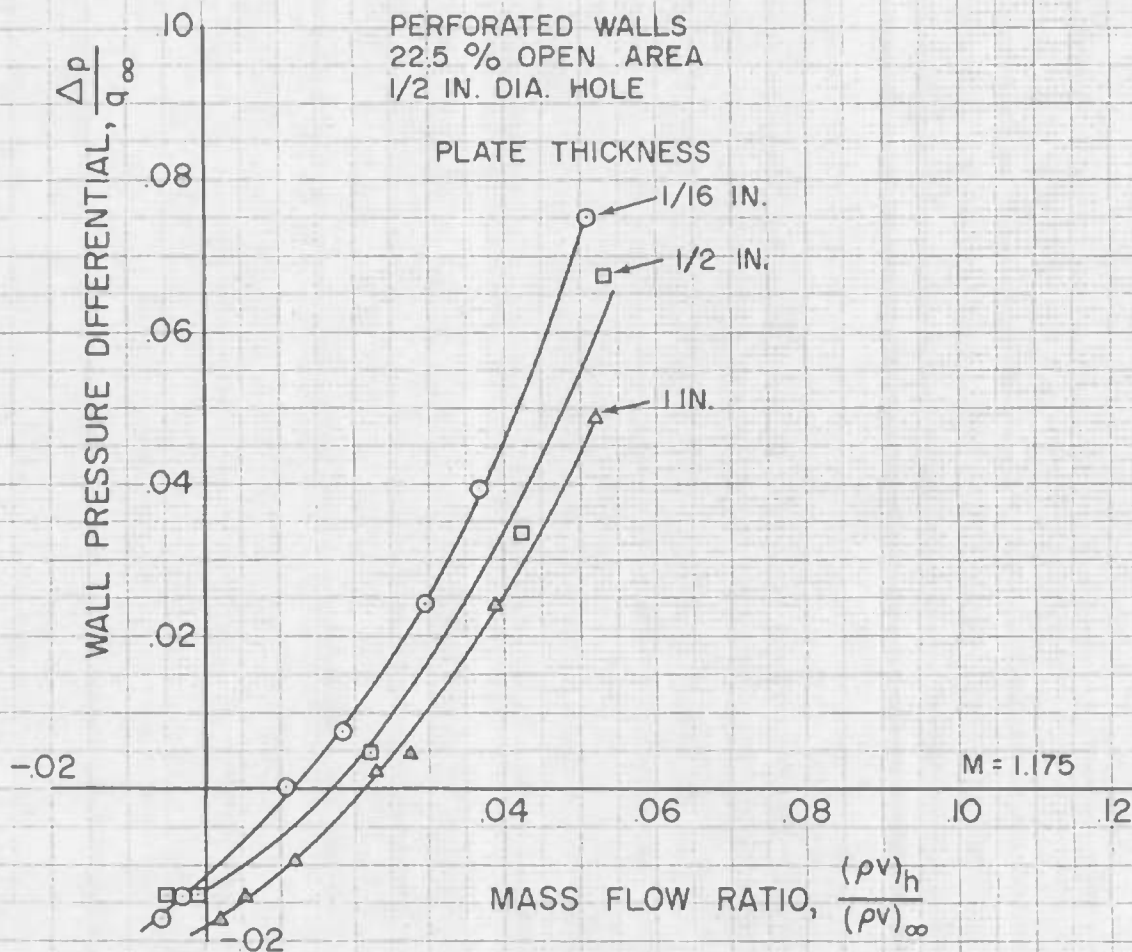


Fig. 5f. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1/2-Inch Diameter Holes;  $M = 1.175$

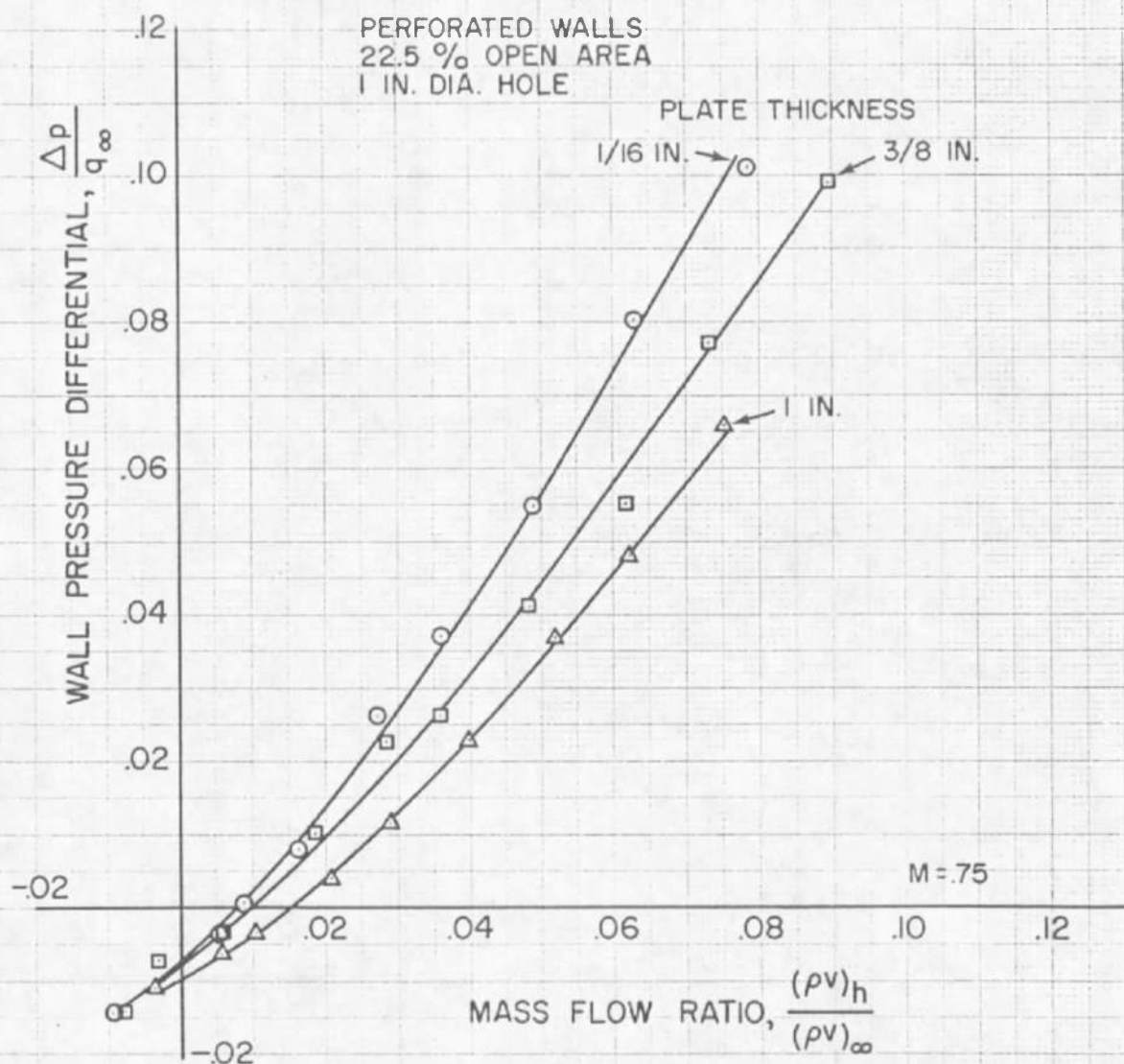


Fig. 6a. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1-Inch Diameter Holes; M = 0.75

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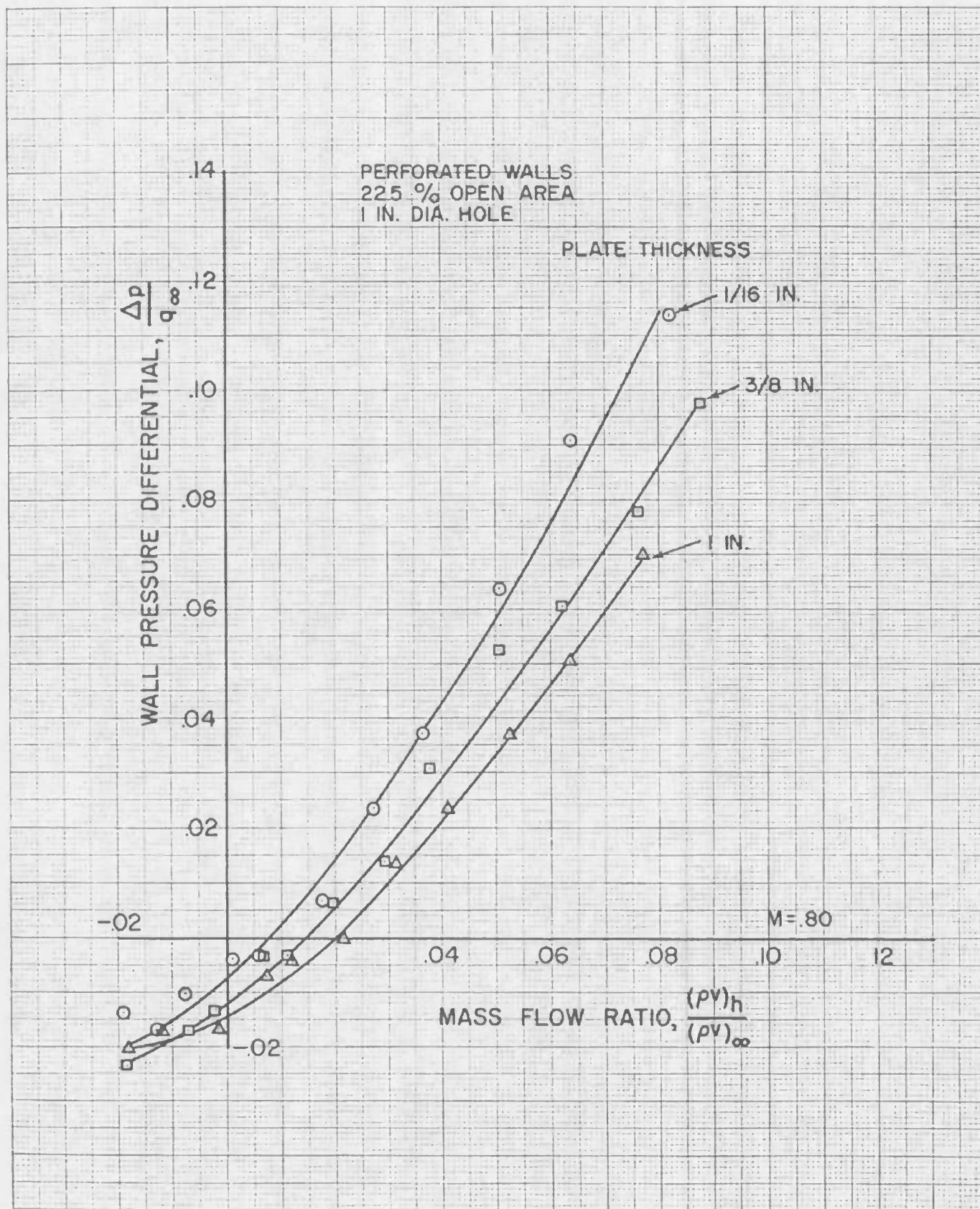
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Fig. 6b. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1-Inch Diameter Holes;  $M = 0.80$

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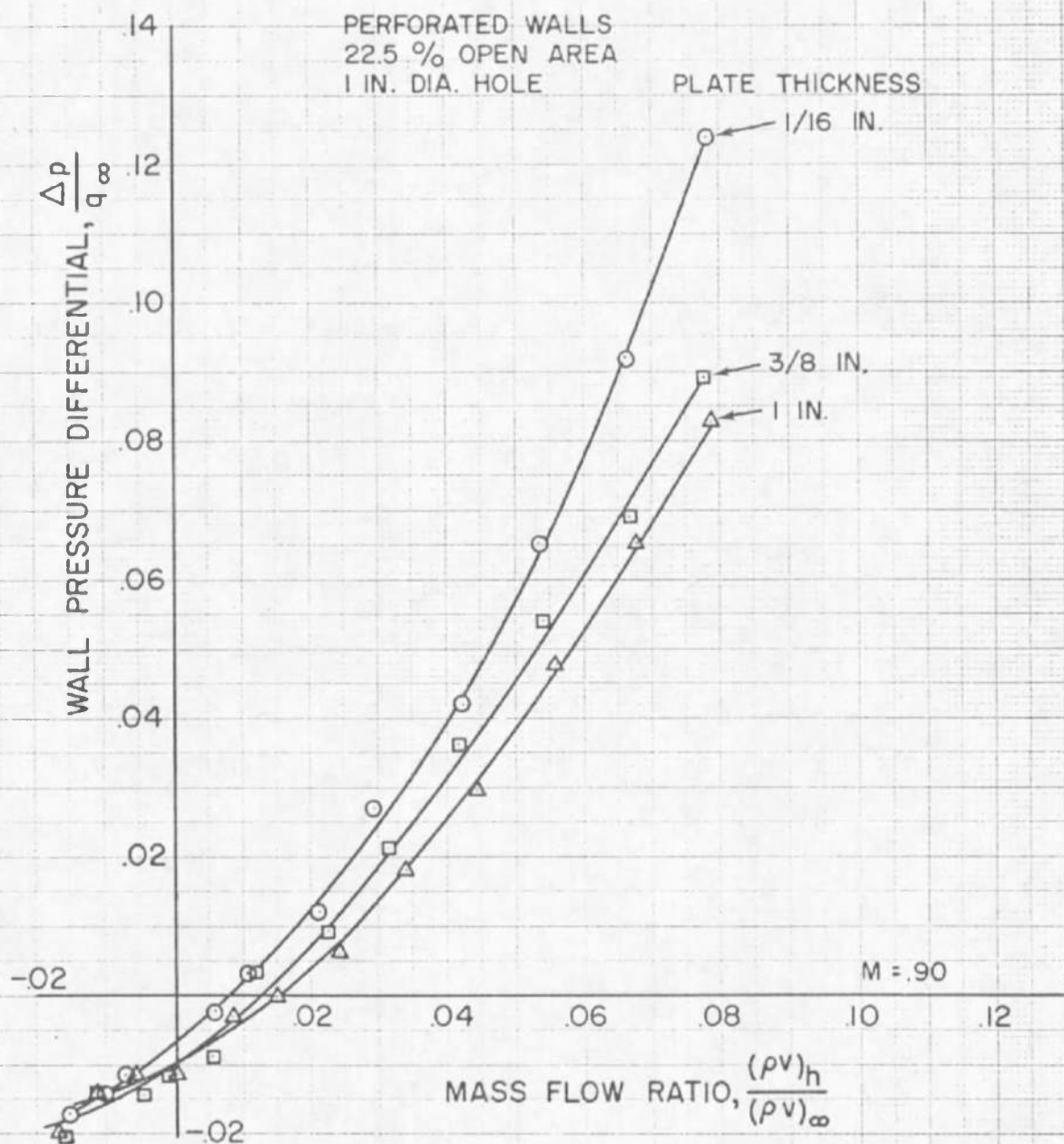


Fig. 6c. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1-Inch Diameter Holes;  $M = 0.90$

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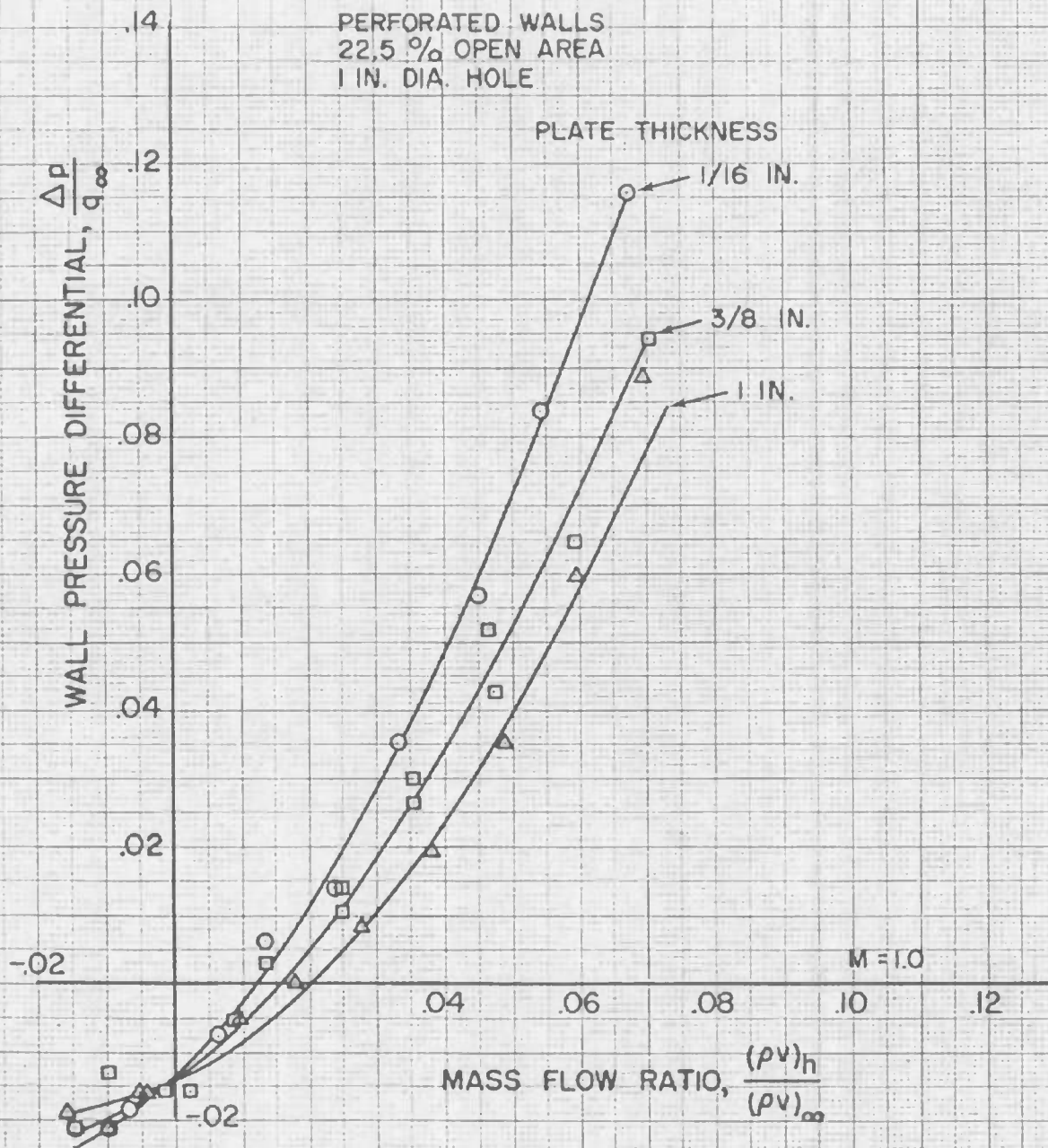
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Fig. 6d. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1-Inch Diameter Holes;  $M = 1.00$

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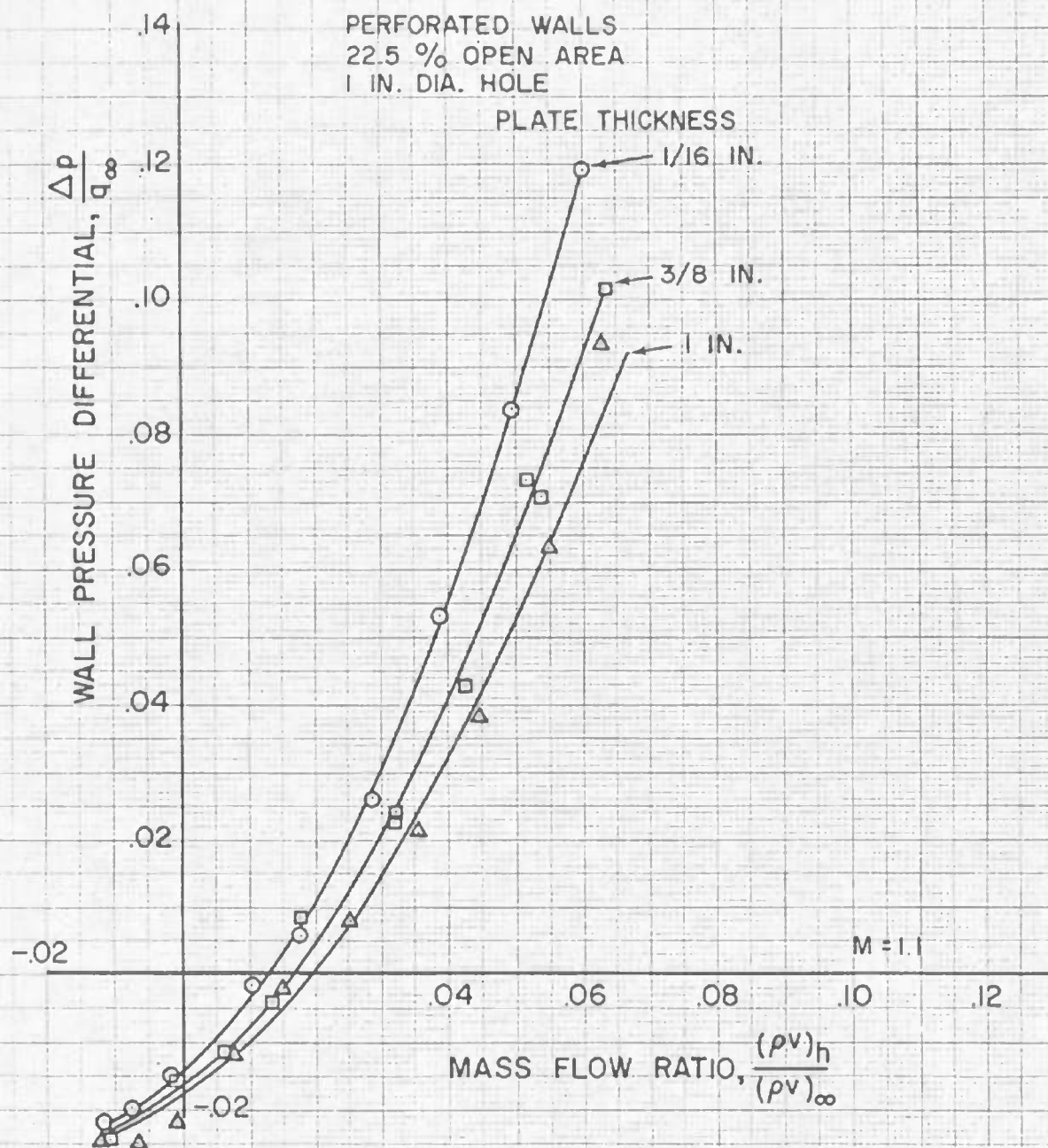


Fig. 6e. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1-Inch Diameter Holes; M = 1.10

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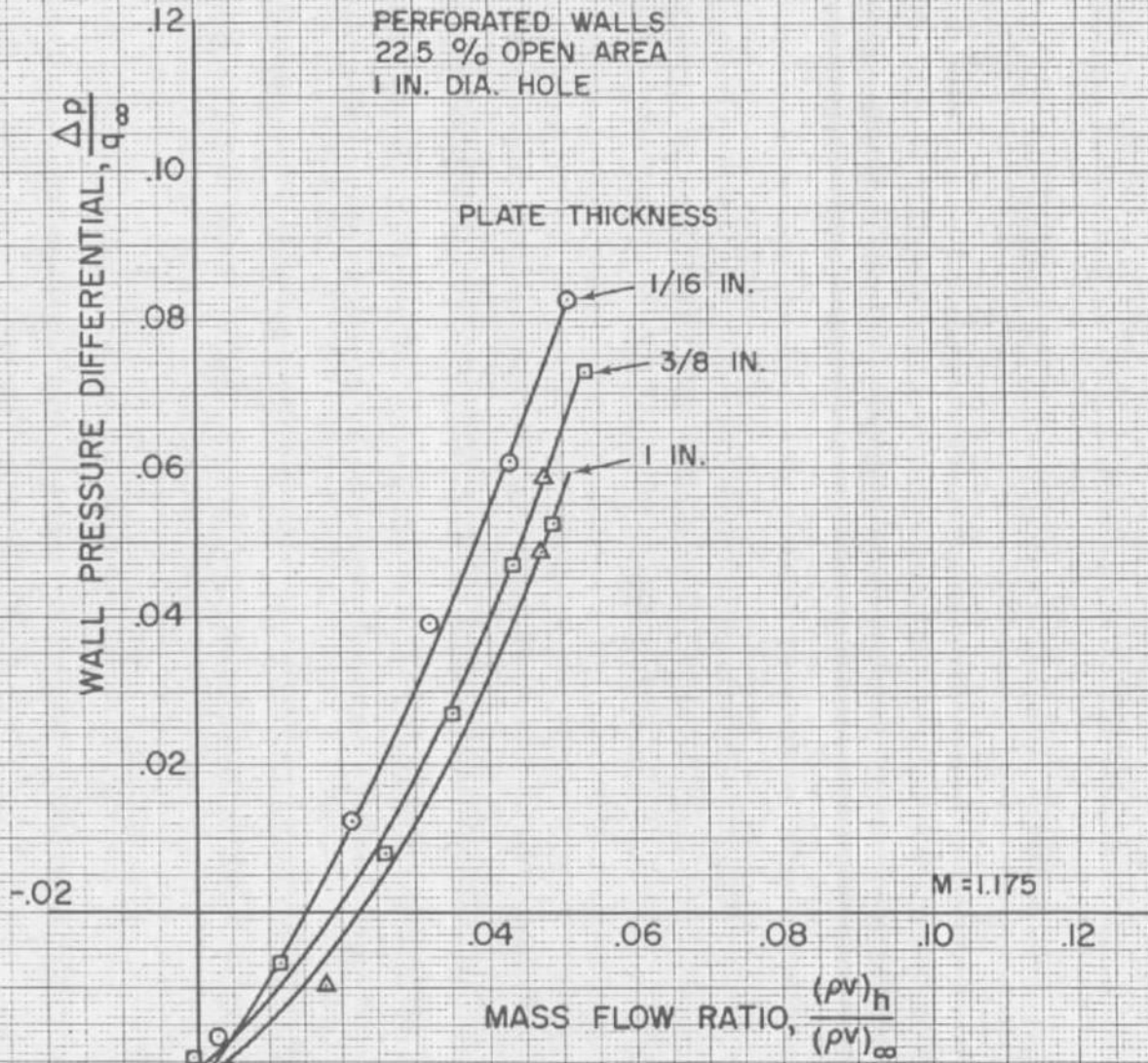


Fig. 6f. Influence of Plate Thickness on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Perforated Wall with 1-Inch Diameter Holes;  $M = 1.175$

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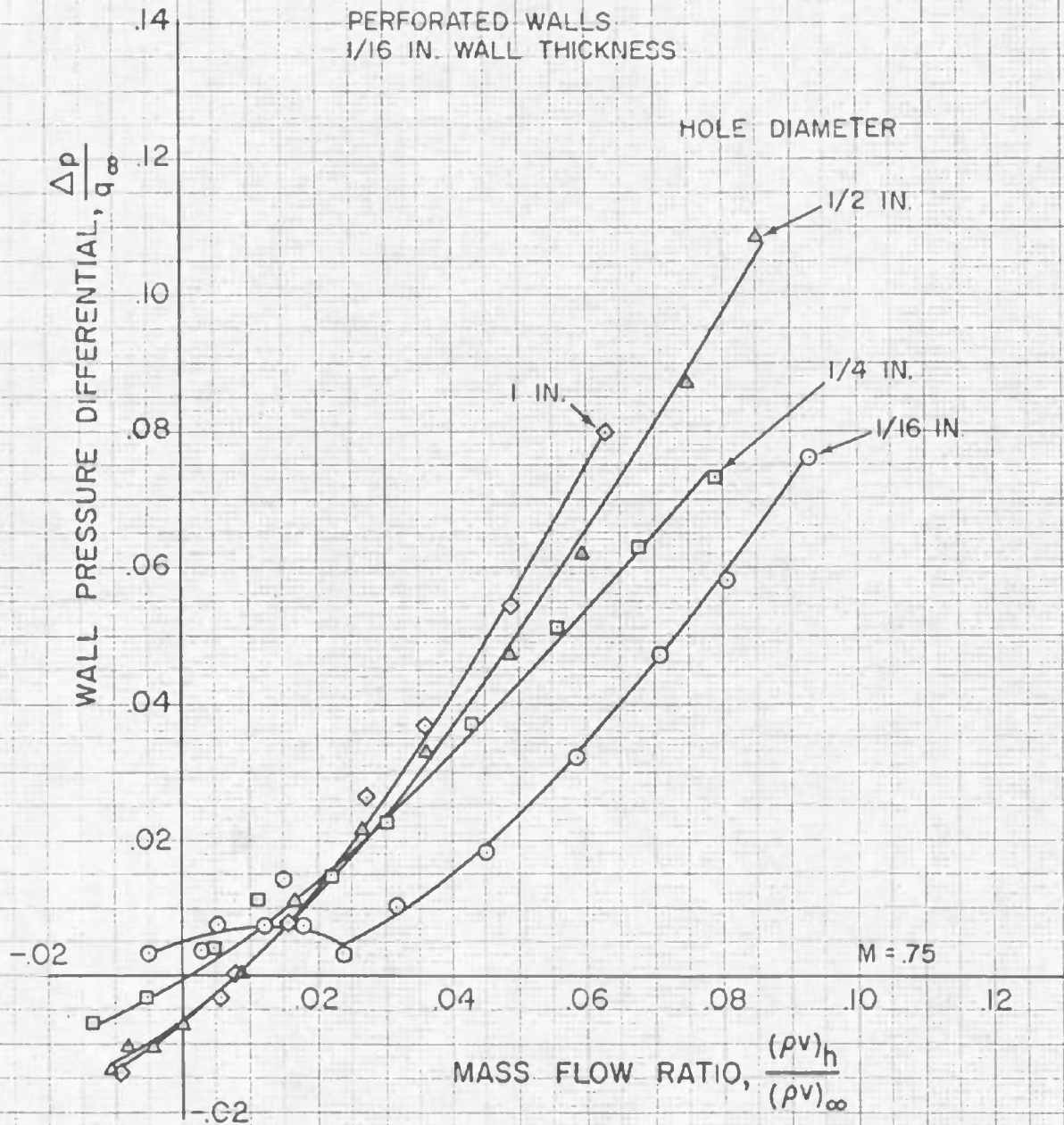


Fig. 7a. Influence of Hole Diameter on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall with 1/16-Inch Plate Thickness; M = 0.75

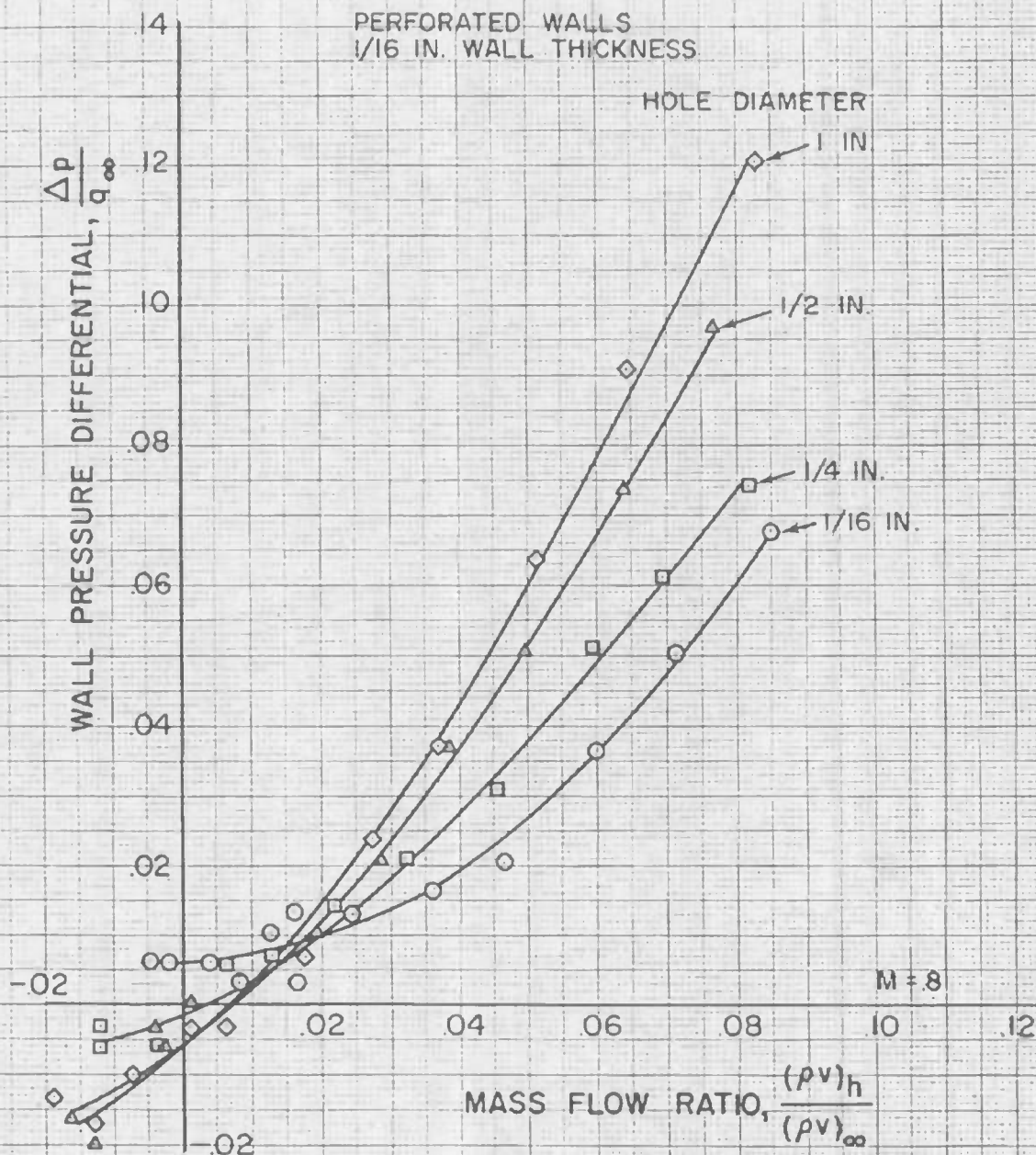


Fig. 7b. Influence of Hole Diameter on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall with 1/16-Inch Plate Thickness;  $M = 0.80$

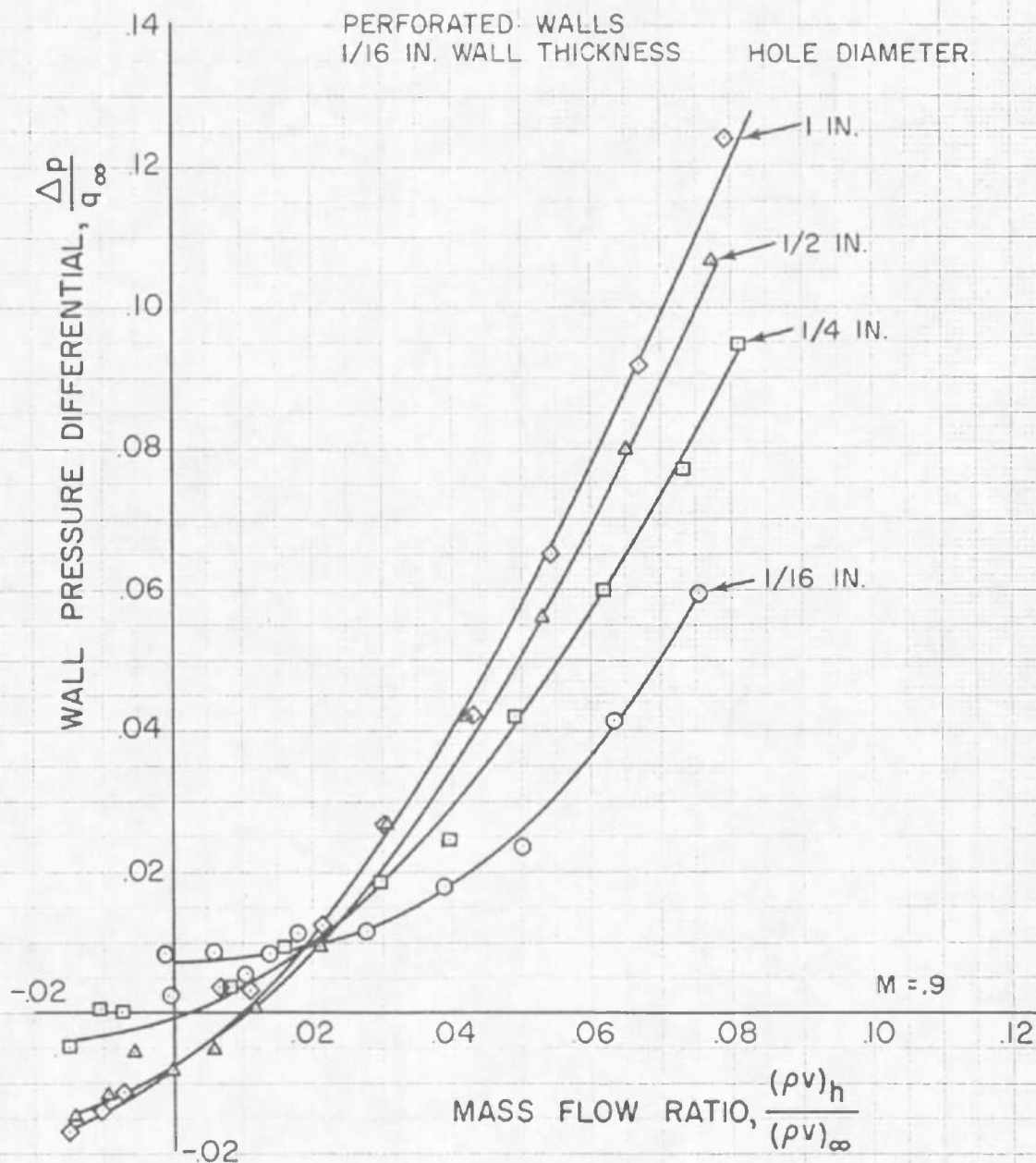


Fig. 7c. Influence of Hole Diameter on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall with 1/16-Inch Plate Thickness;  $M = 0.90$

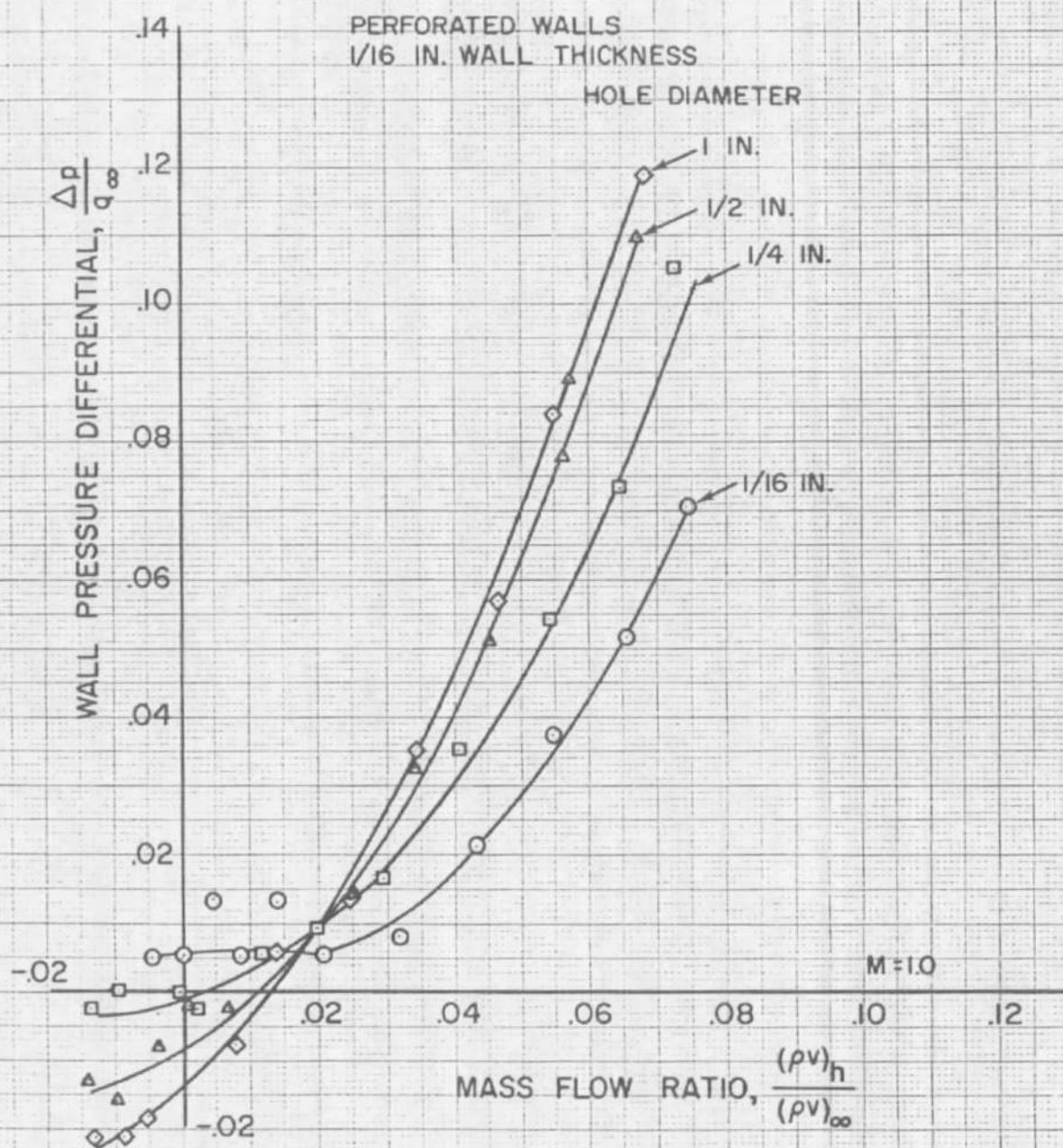


Fig. 7d. Influence of Hole Diameter on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall with 1/16-Inch Plate Thickness;  $M = 1.00$

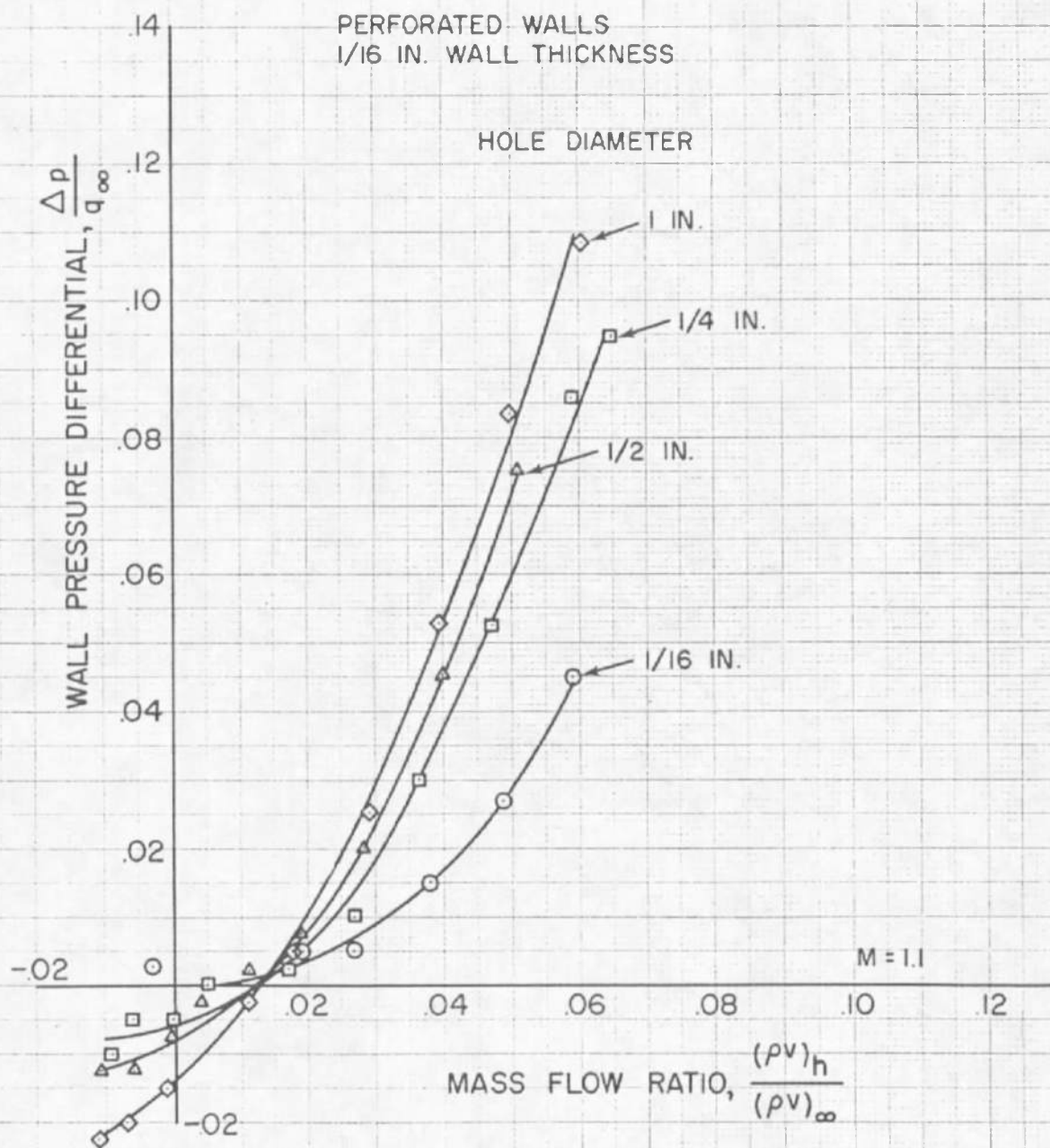


Fig. 7e. Influence of Hole Diameter on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall with 1/16-Inch Plate Thickness;  $M = 1.10$

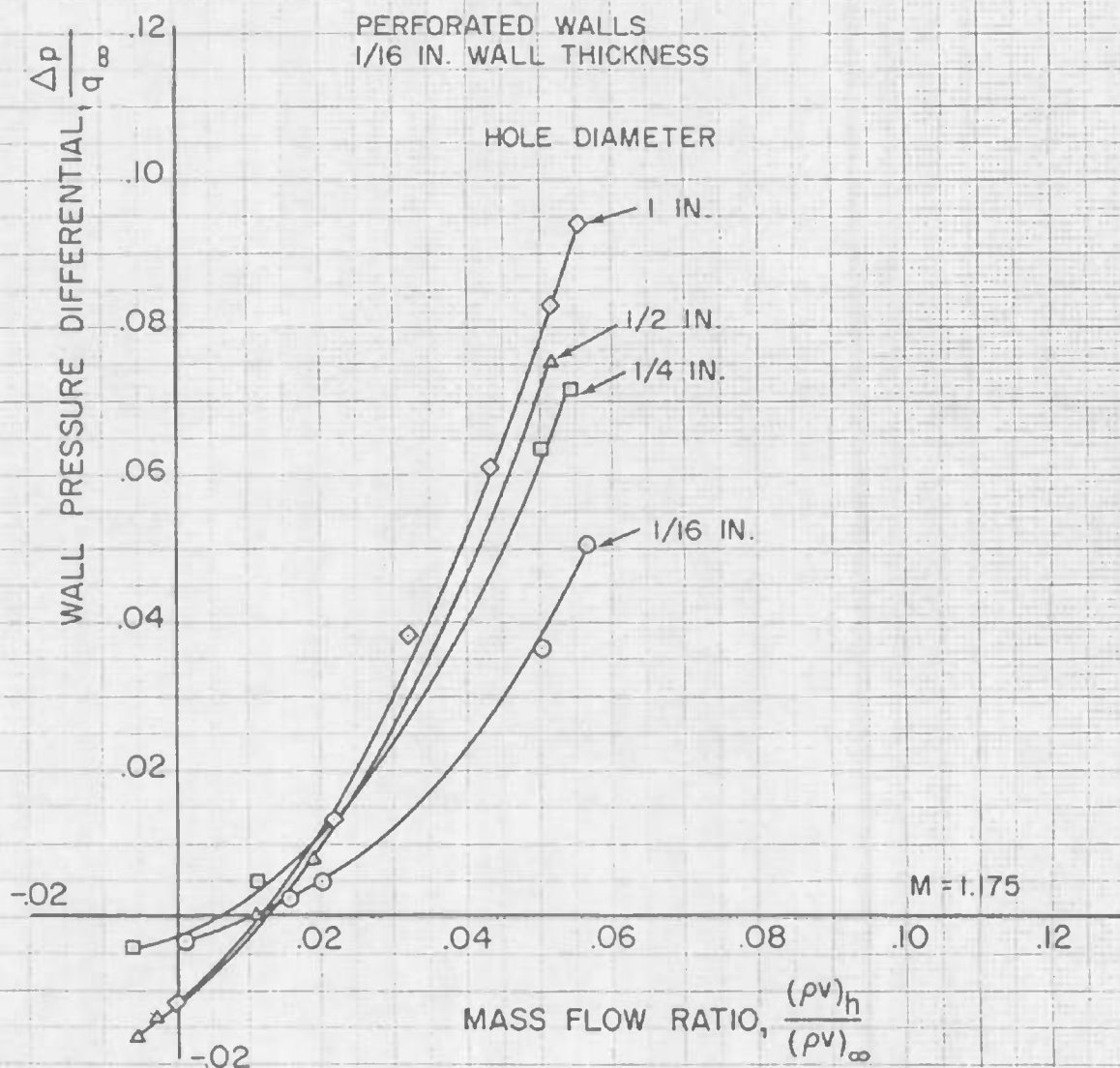
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Fig. 7f. Influence of Hole Diameter on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall with 1/16-Inch Plate Thickness;  $M = 1.175$

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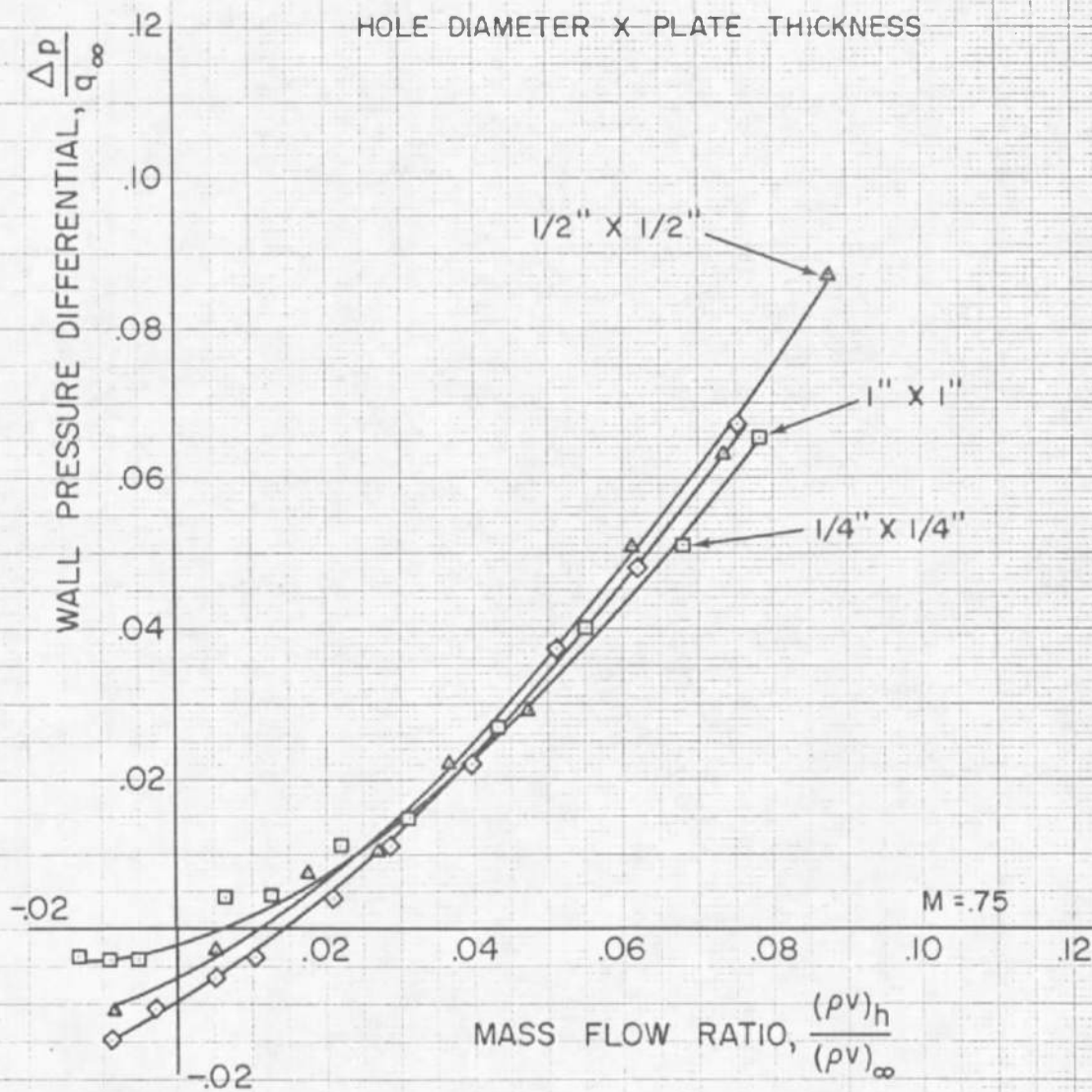


Fig. 8a. Influence of Hole Size on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall when the Ratio of Hole Diameter to Plate Thickness is Equal to Unity;  $M = 0.75$

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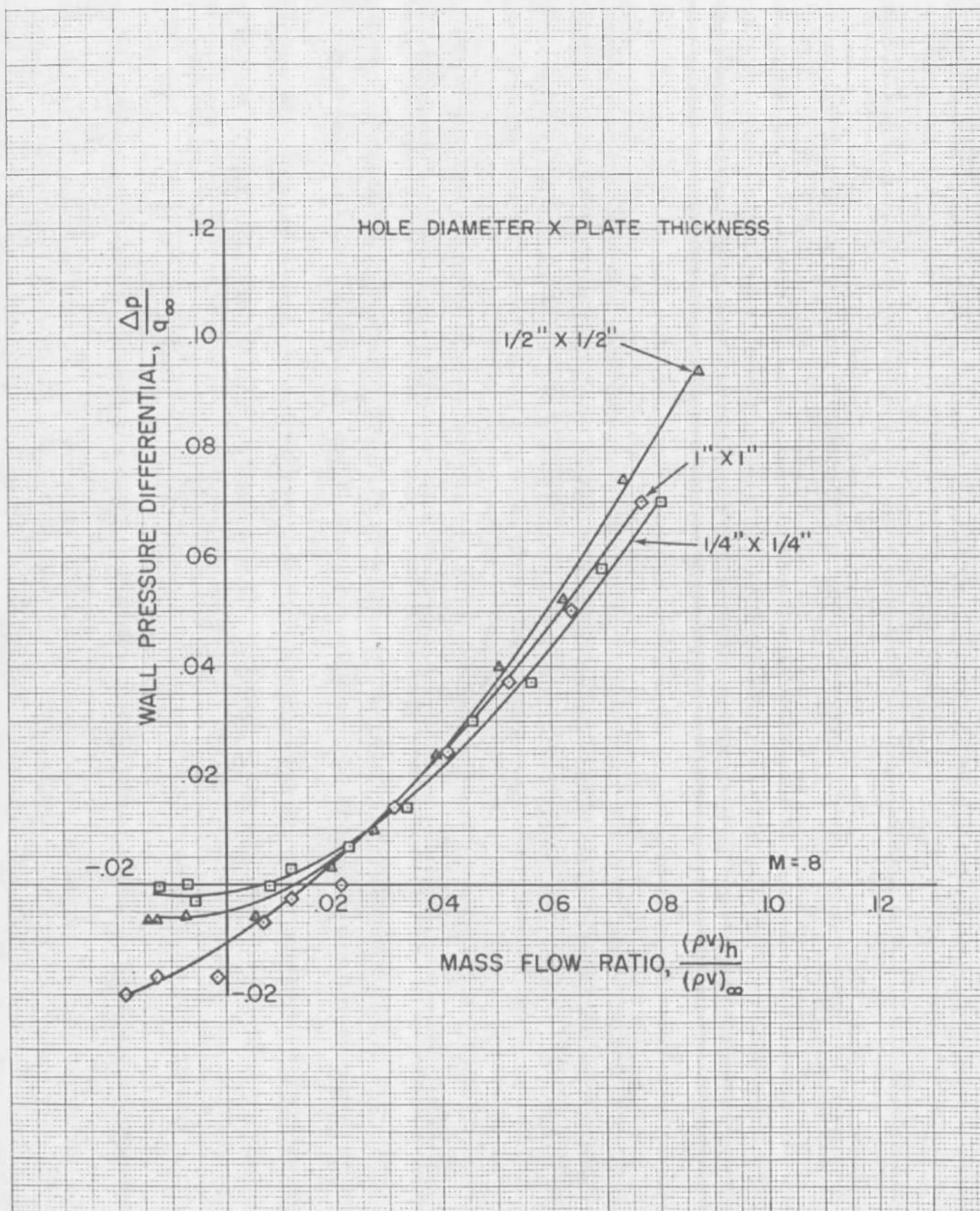


Fig. 8b. Influence of Hole Size on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall when the Ratio of Hole Diameter to Plate Thickness is Equal to Unity;  $M = 0.80$

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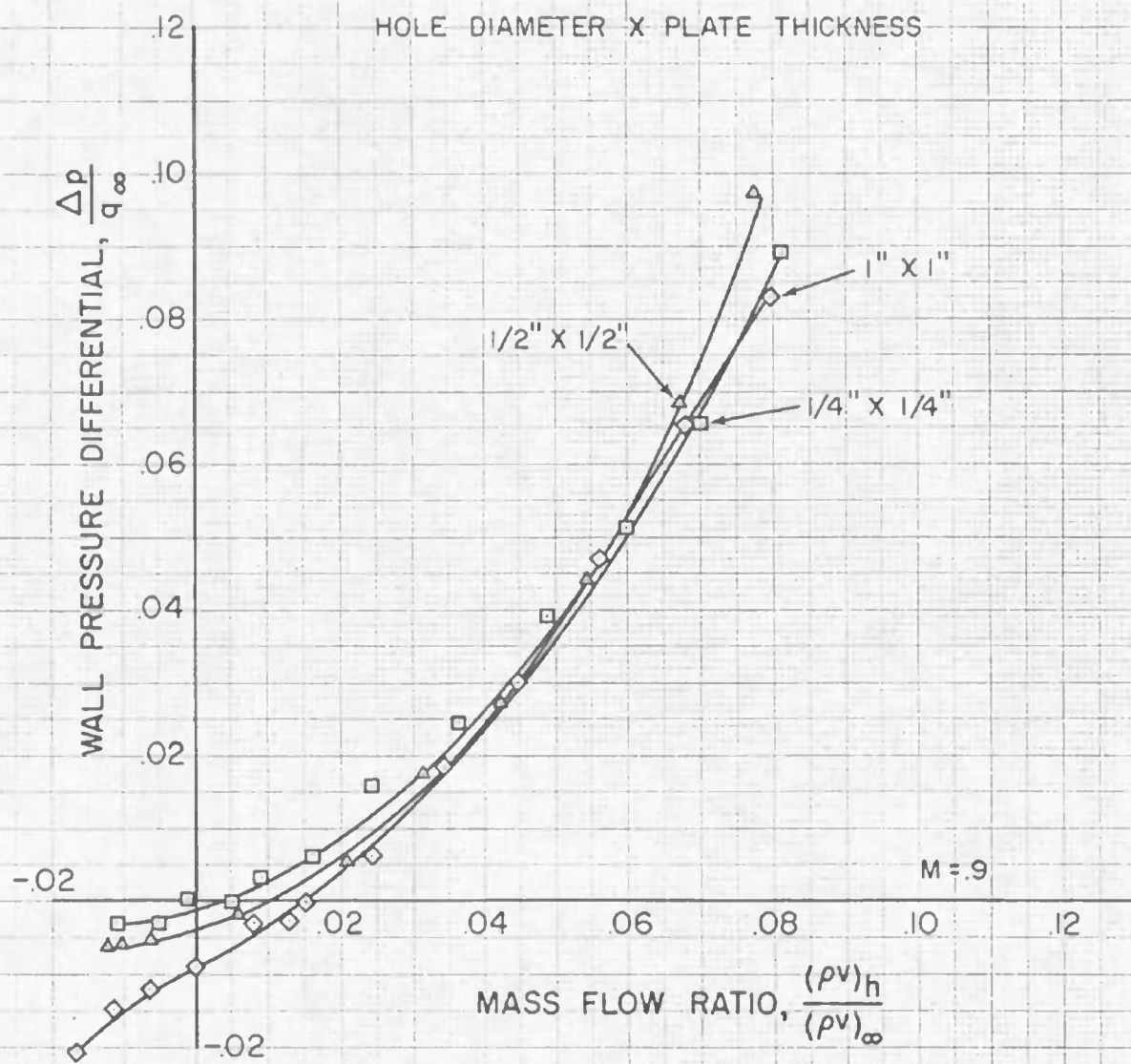


Fig. 8c. Influence of Hole Size on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall when the Ratio of Hole Diameter to Plate Thickness is Equal to Unity;  $M = 0.90$

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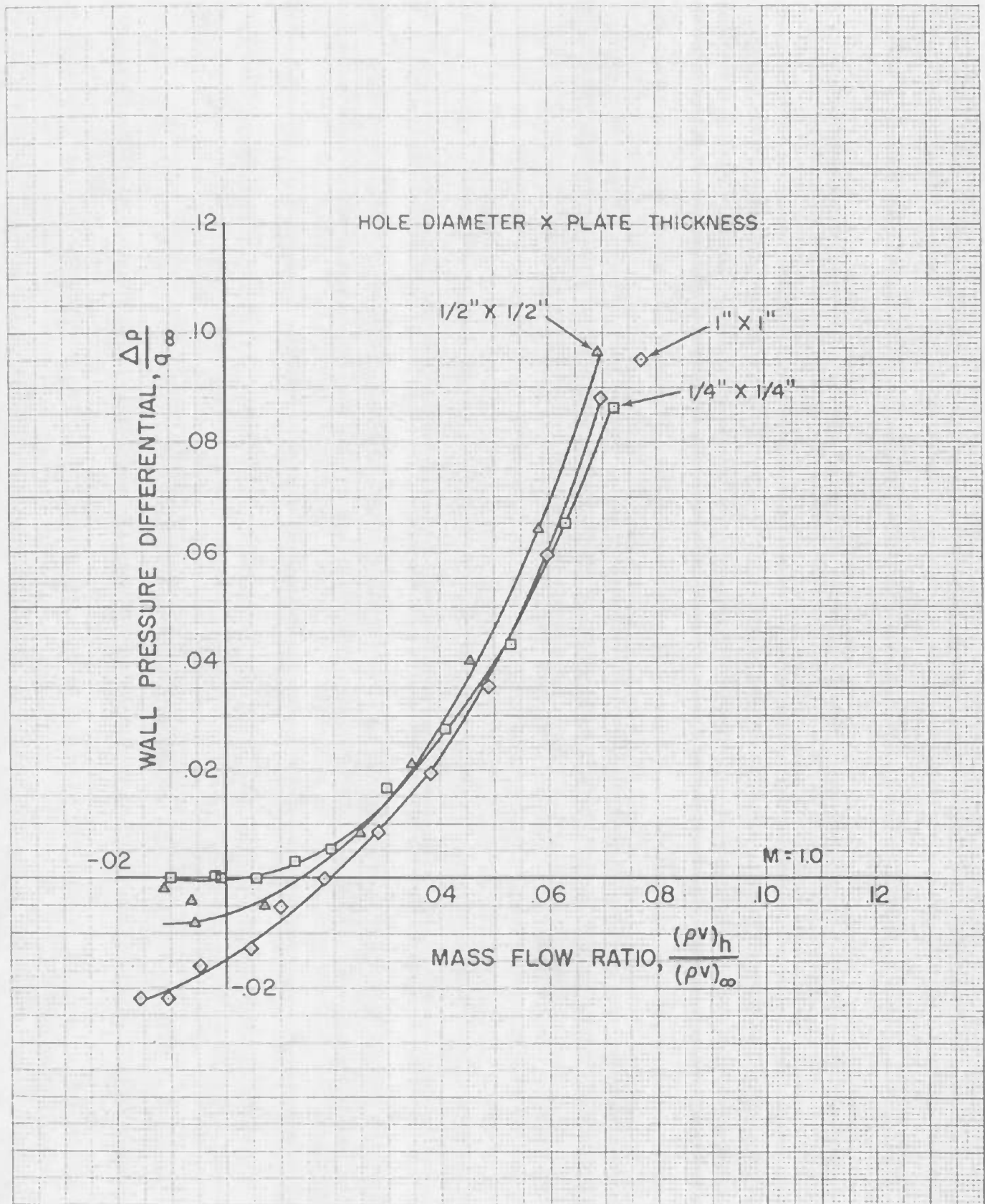
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Fig. 8d. Influence of Hole Size on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall when the Ratio of Hole Diameter to Plate Thickness is Equal to Unity;  $M = 1.00$

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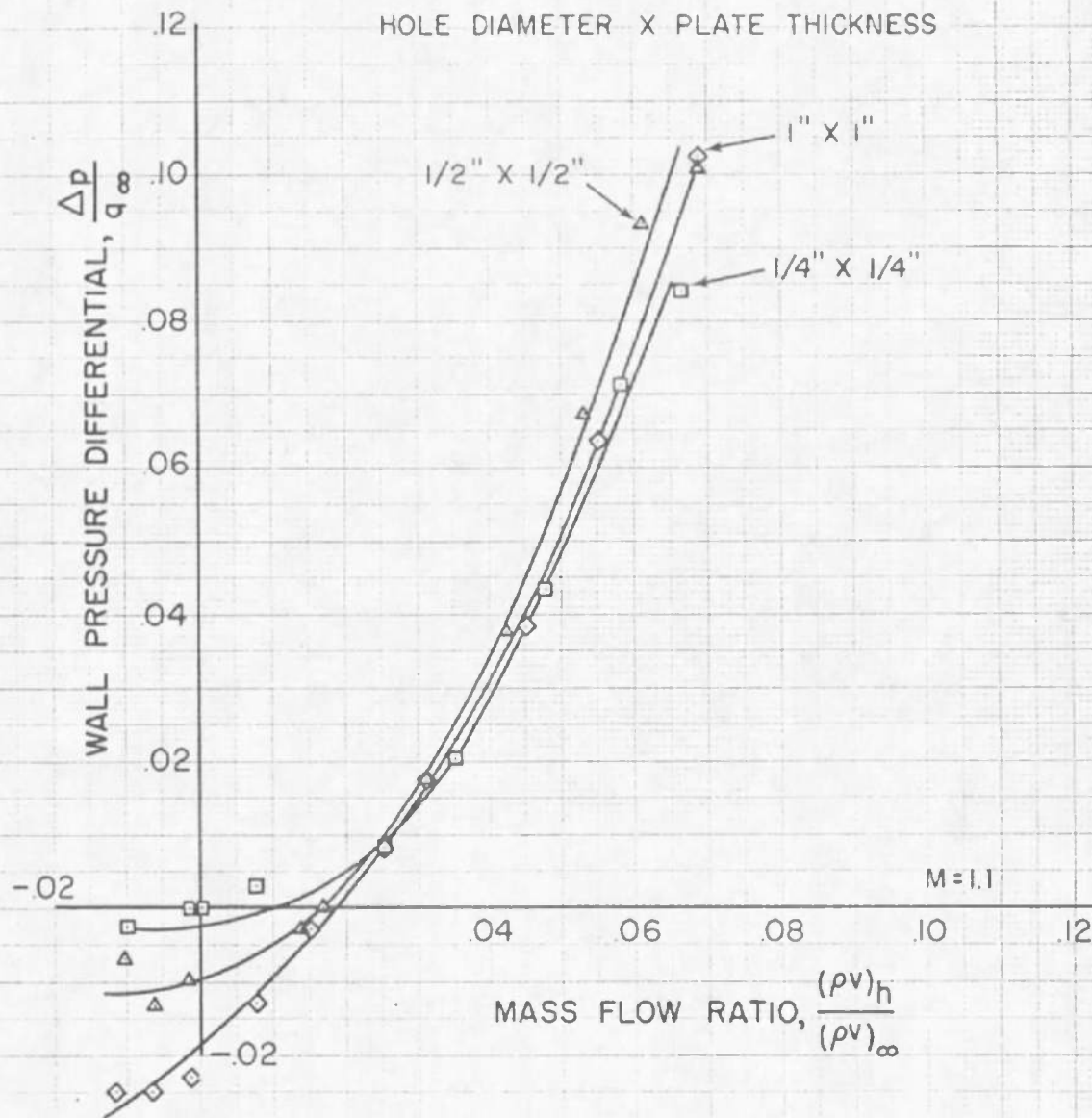


Fig. 8e. Influence of Hole Size on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall when the Ratio of Hole Diameter to Plate Thickness is Equal to Unity;  $M = 1.10$

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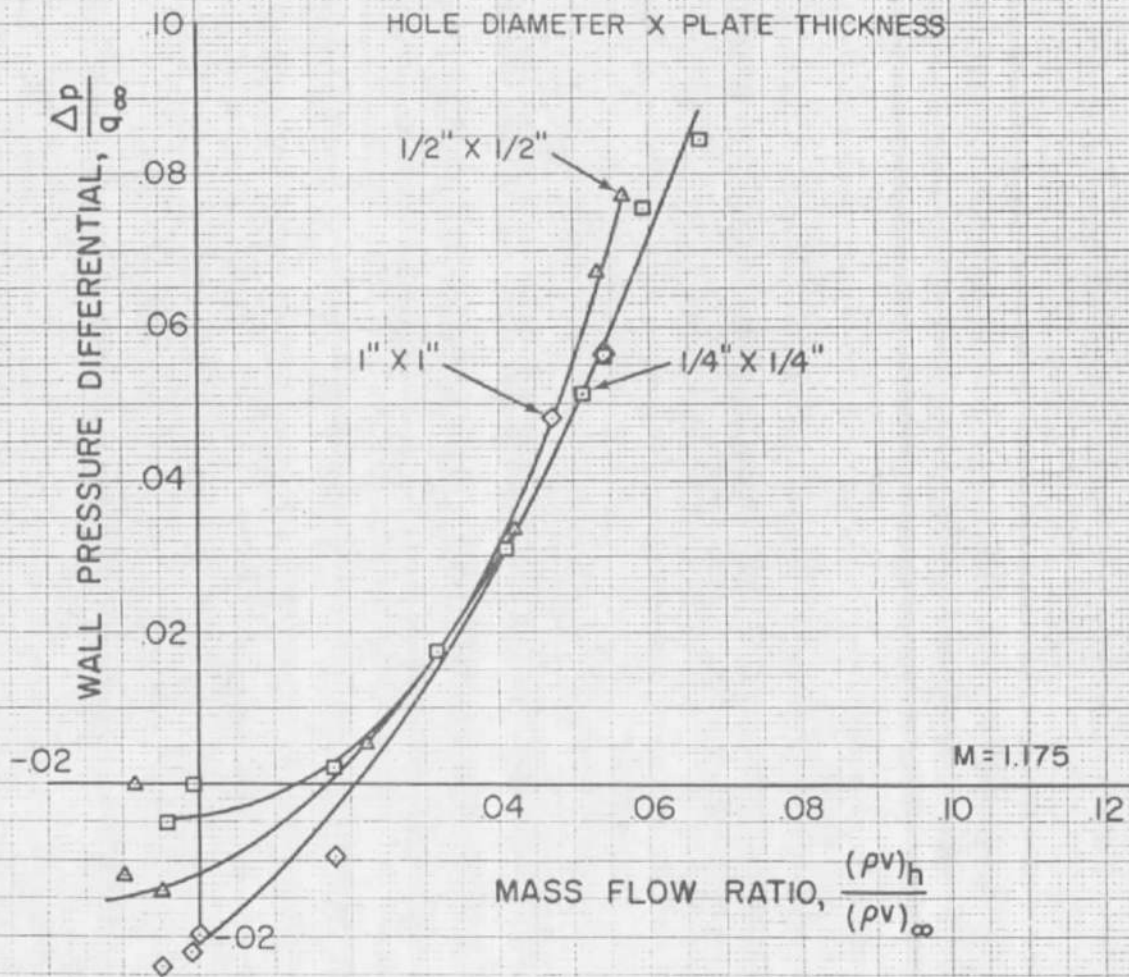
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Fig. 8f. Influence of Hole Size on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall when the Ratio of Hole Diameter to Plate Thickness is Equal to Unity;  $M = 1.175$

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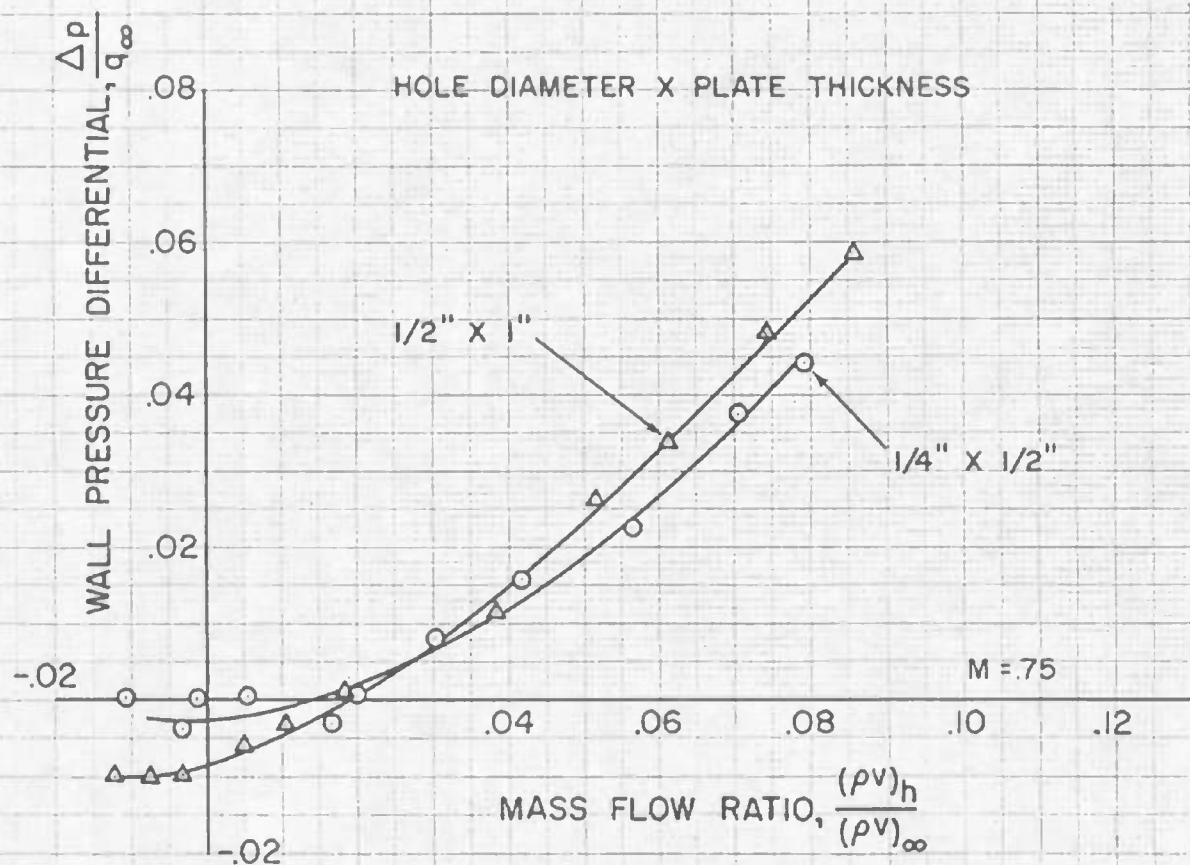


Fig. 9a. Influence of Hole Size on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall when the Ratio of Hole Diameter to Plate Thickness is Equal to 0.5;  $M = 0.75$

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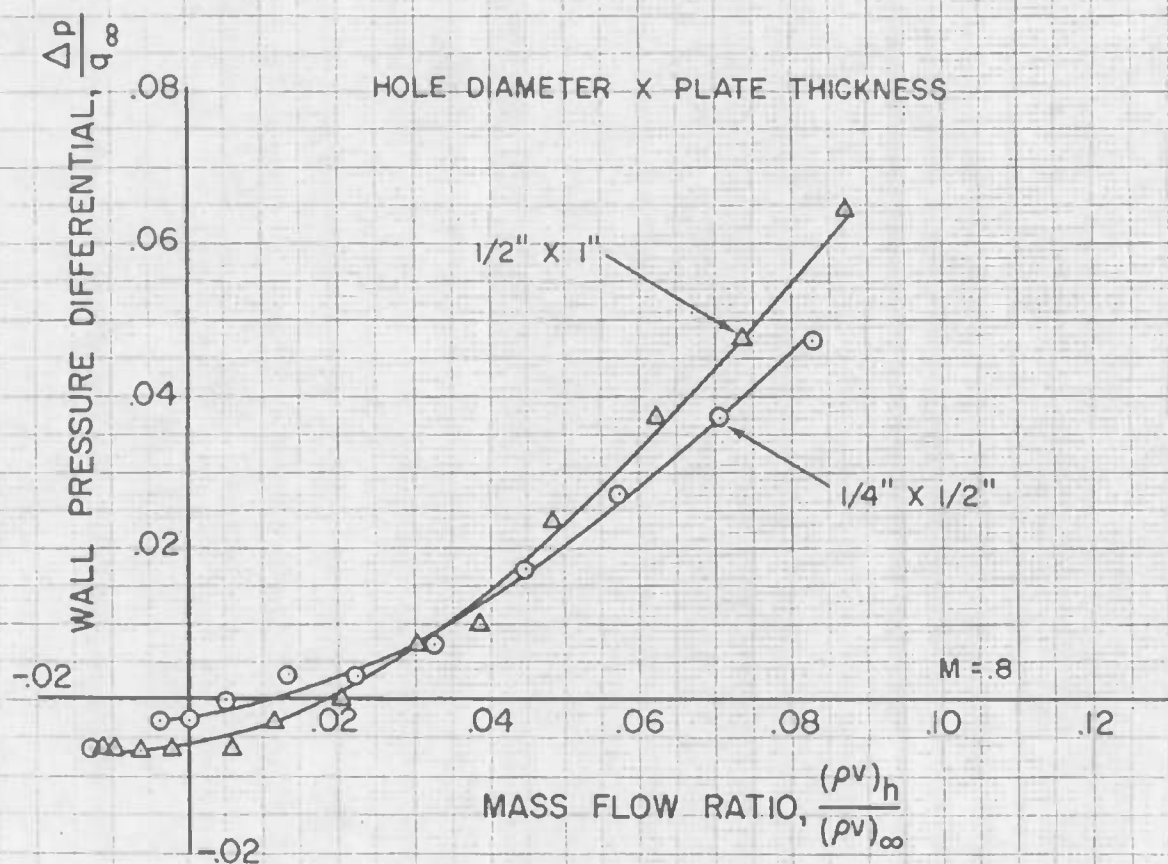


Fig. 9b. Influence of Hole Size on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall when the Ratio of Hole Diameter to Plate Thickness is Equal to 0.5,  $M = 0.80$

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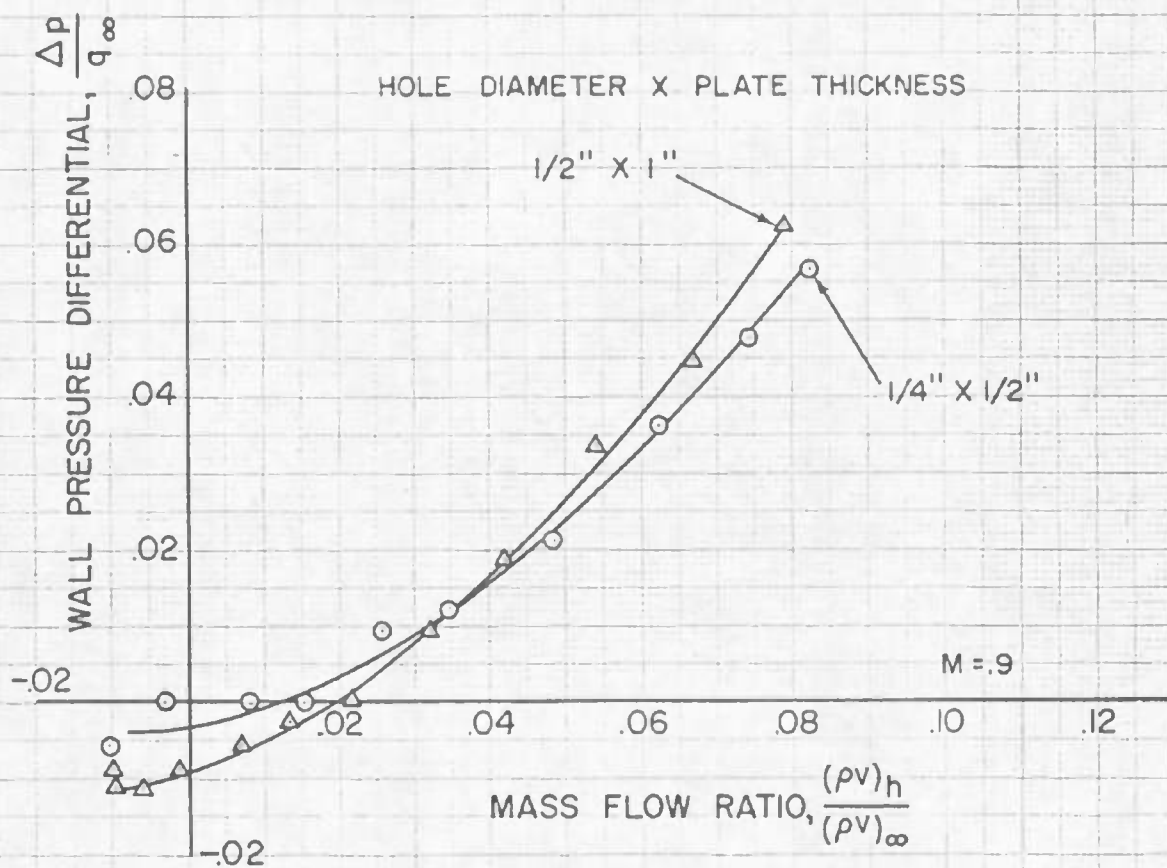


Fig. 9c. Influence of Hole Size on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall when the Ratio of Hole Diameter to Plate Thickness is Equal to 0.5; M = 0.90

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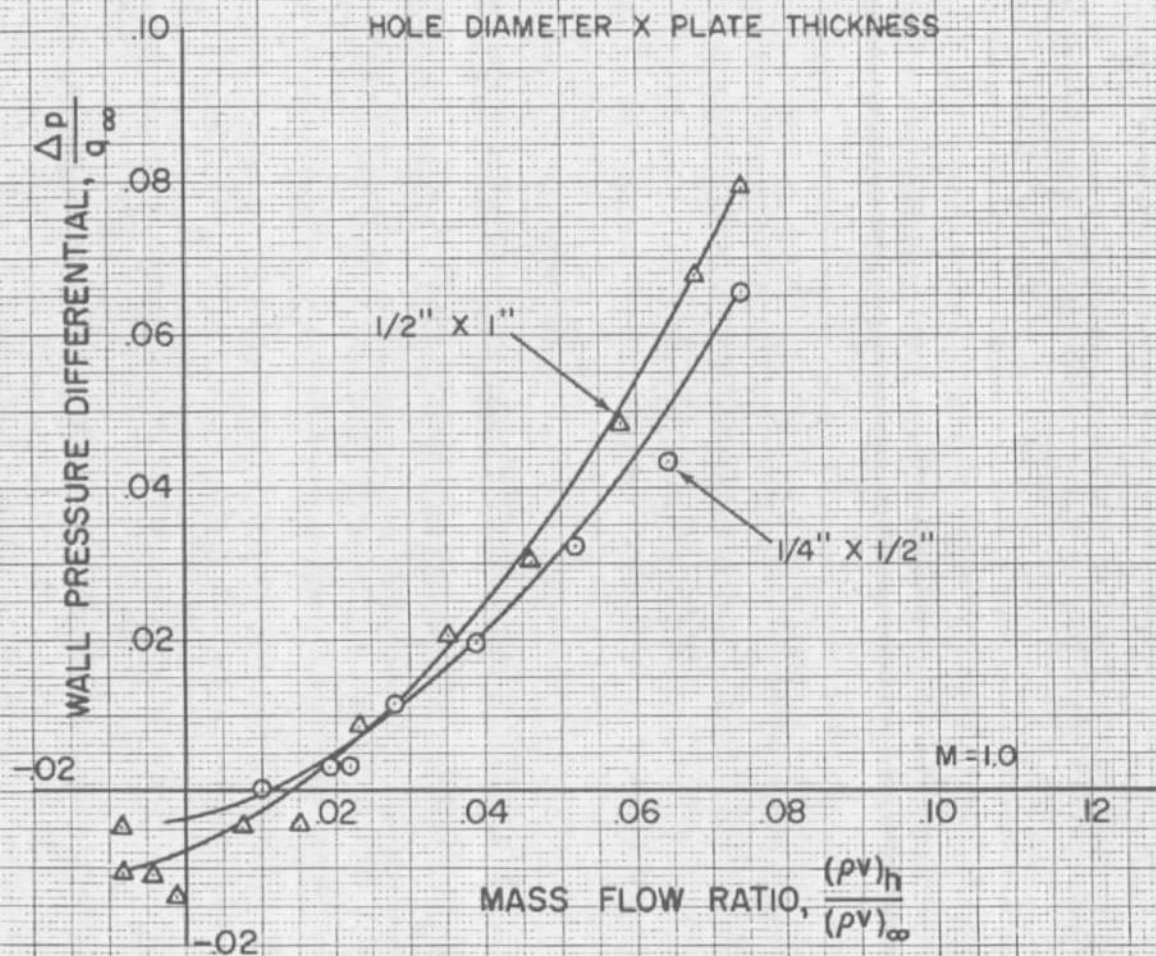


Fig. 9d. Influence of Hole Size on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall when the Ratio of Hole Diameter to Plate Thickness is Equal to 0.5;  $M = 1.00$

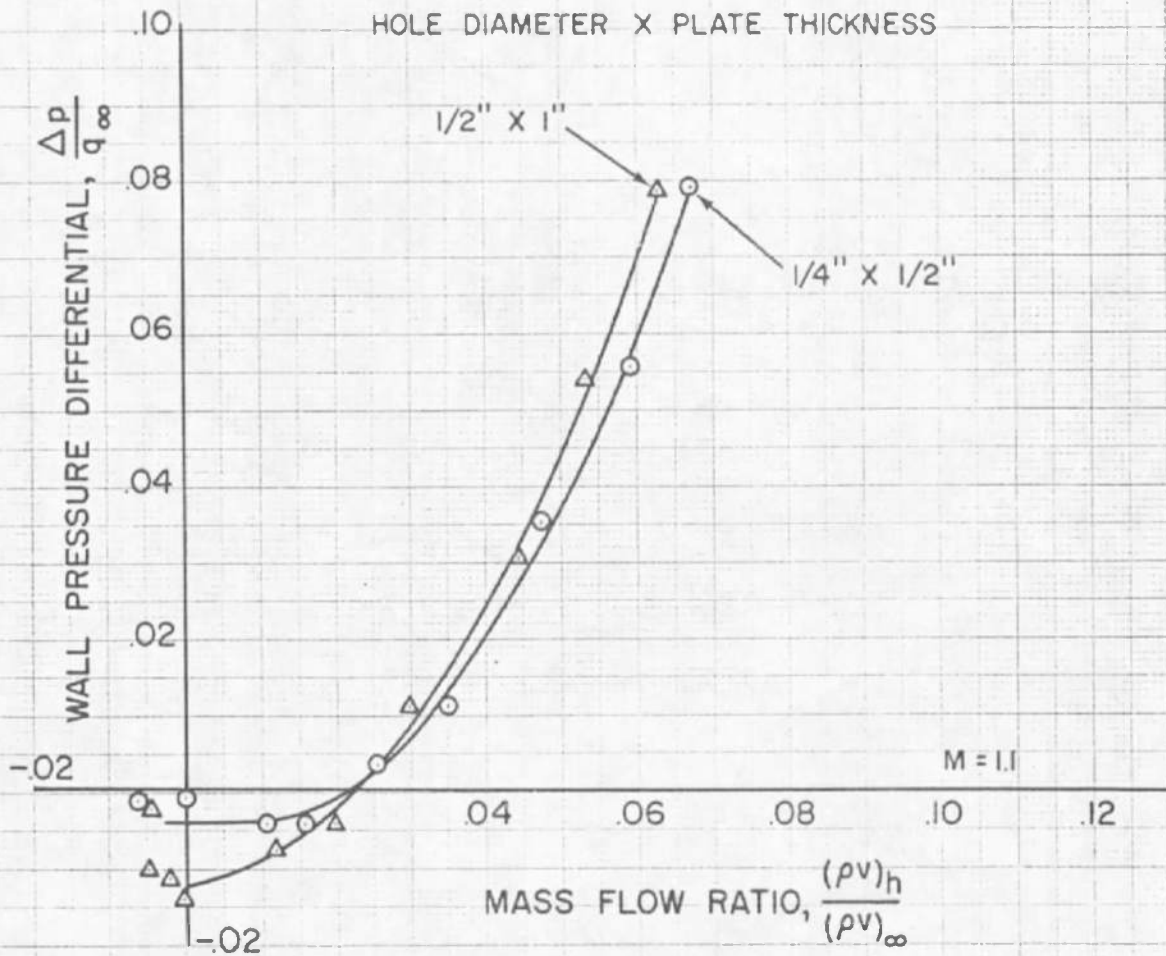


Fig. 9e. Influence of Hole Size on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall when the Ratio of Hole Diameter to Plate Thickness is Equal to 0.5;  $M = 1.10$

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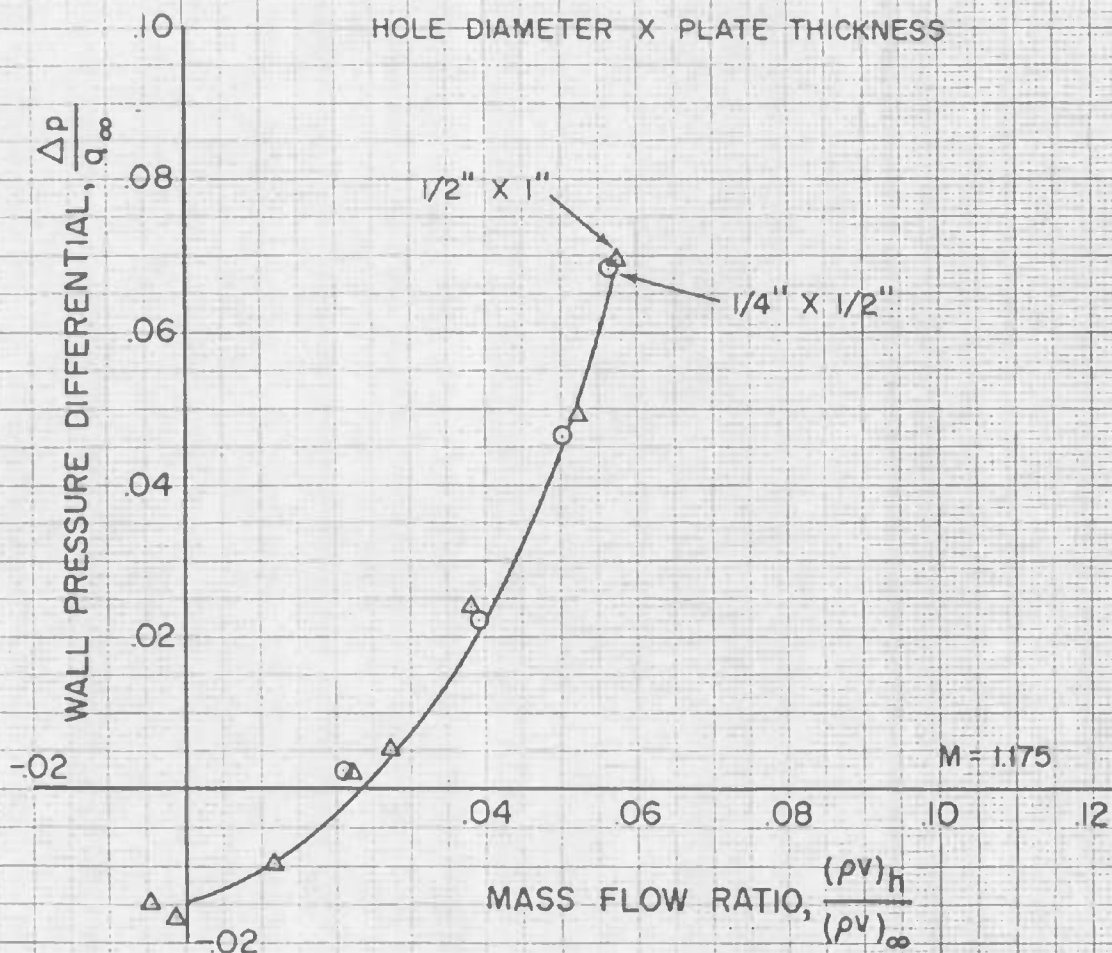
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Fig. 9f. Influence of Hole Size on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall when the Ratio of Hole Diameter to Plate Thickness is Equal to 0.5;  $M = 1.175$

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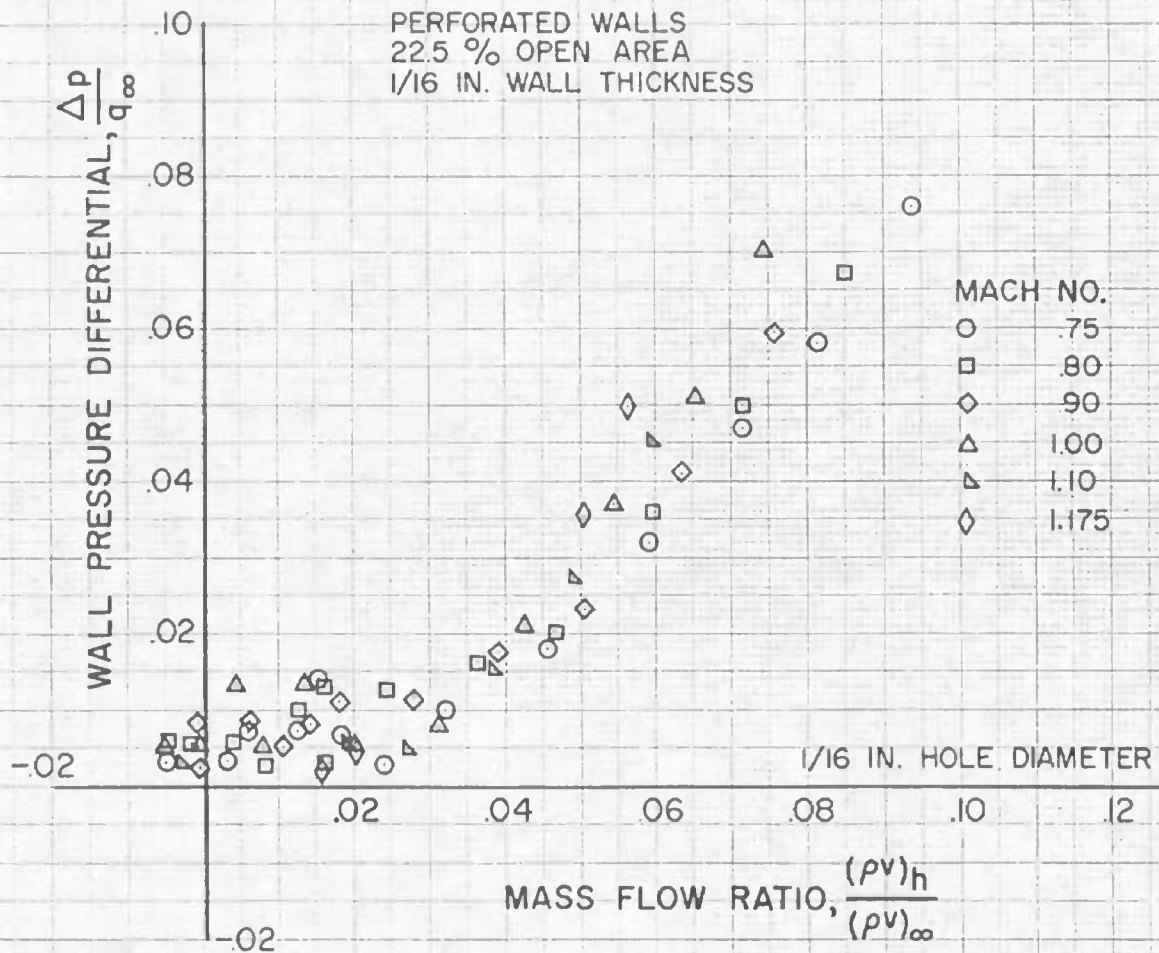


Fig. 10a. Influence of Mach Number on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall with Various Hole Diameters and 1/16-Inch Plate Thickness; 1/16-Inch Hole Diameter

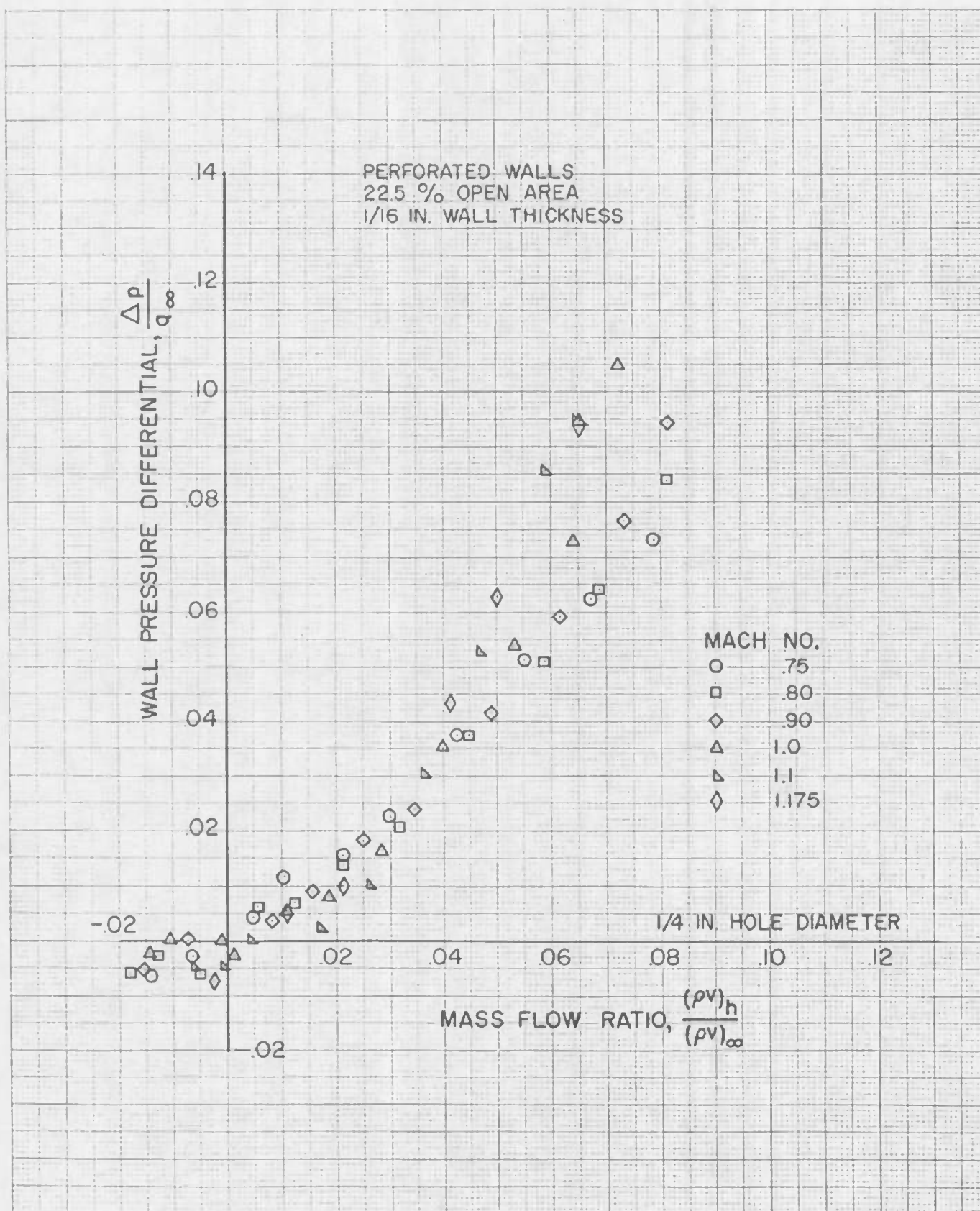


Fig. 10b. Influence of Mach Number on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall with Various Hole Diameters and 1/16-Inch Plate Thickness; 1/4-Inch Hole Diameter

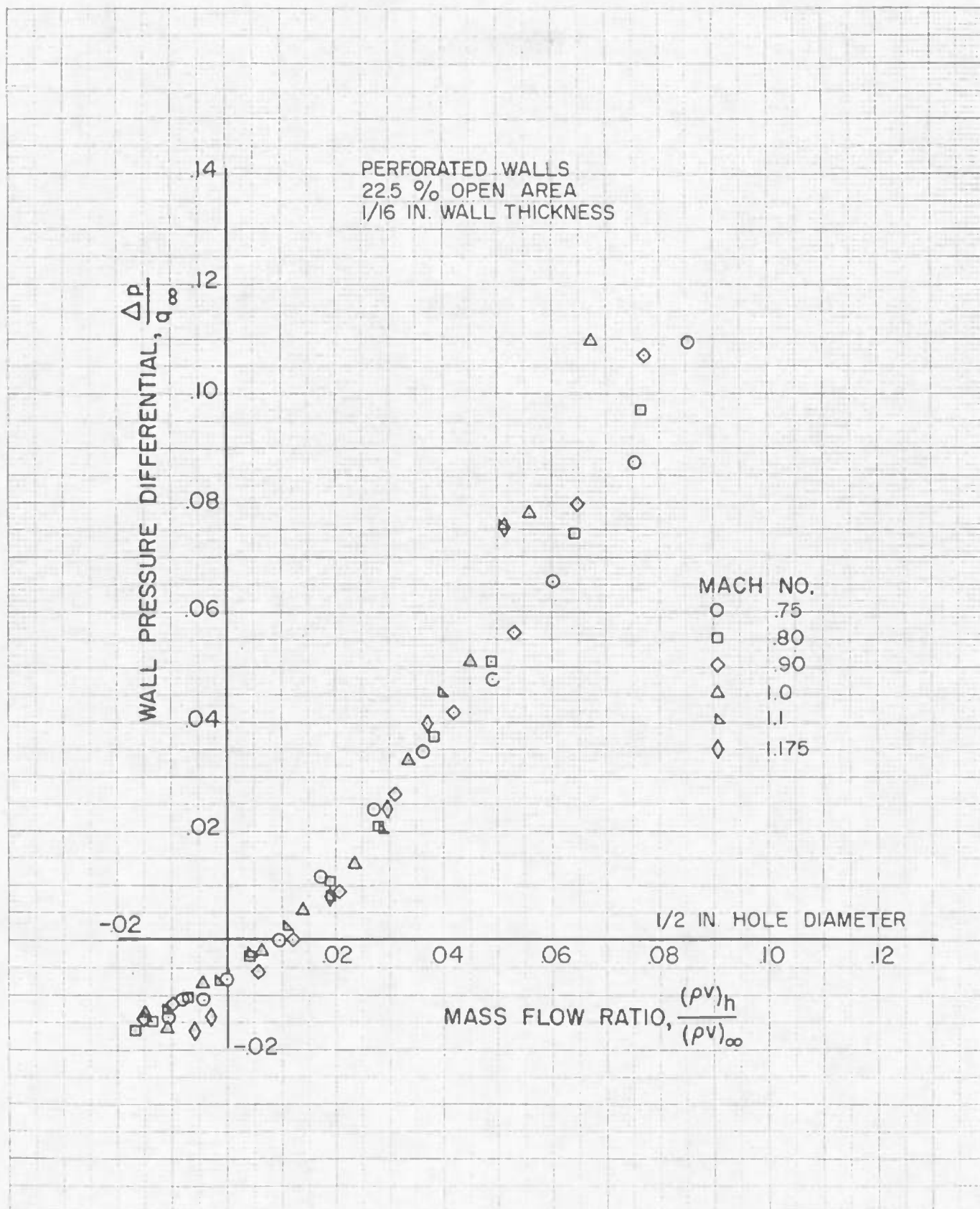


Fig. 10c. Influence of Mach Number on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall with Various Hole Diameters and 1/16-Inch Plate Thickness; 1/2-Inch Hole Diameter

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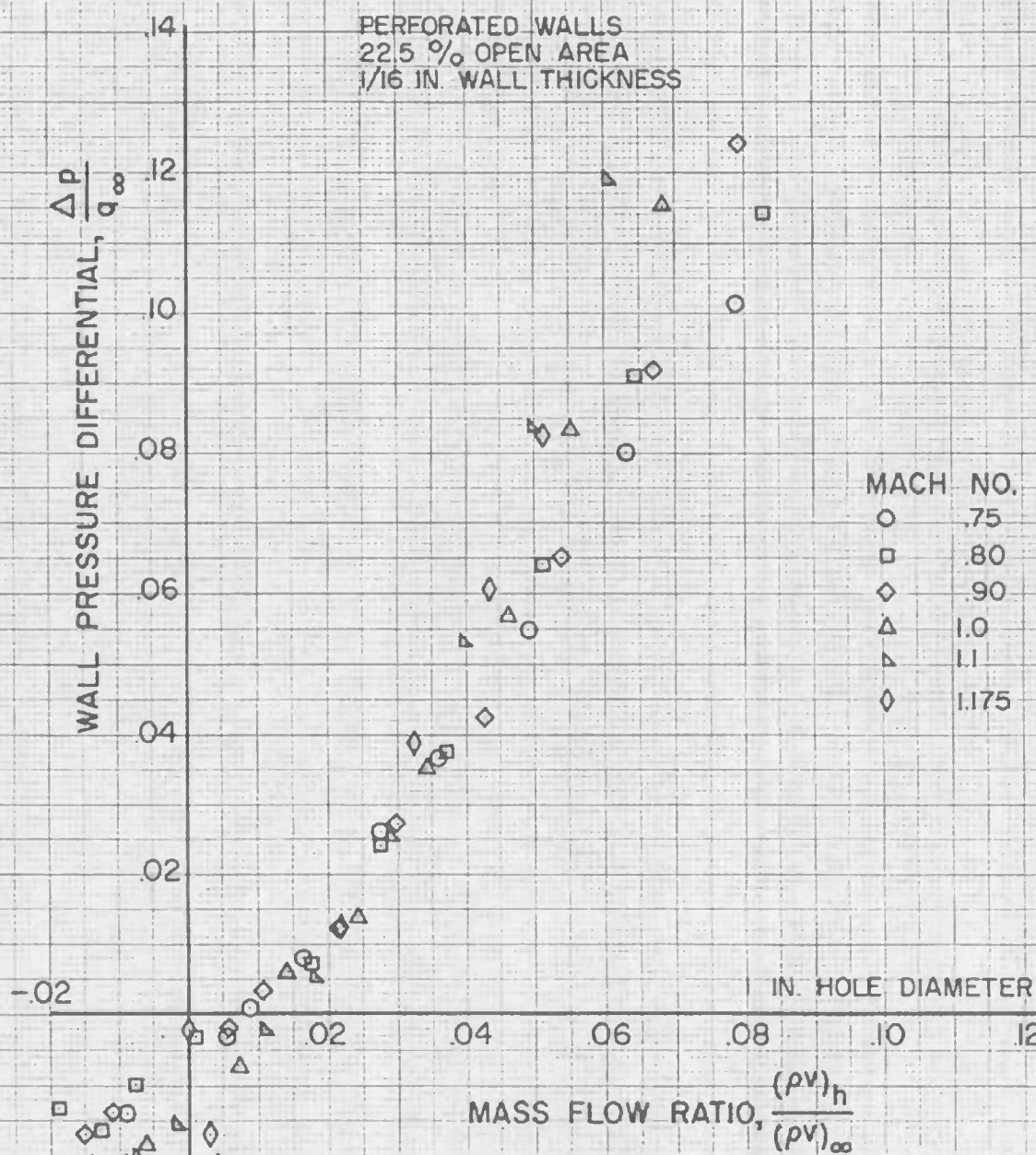


Fig. 10d. Influence of Mach Number on the Cross-Flow Characteristics of a 22.5-Percent Open-Area Wall with Various Hole Diameters and 1/16-Inch Plate Thickness; 1-Inch Hole Diameter

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